[COMMITTEE PRINT]

A MULTI-YEAR FRAMEWORK FOR FEDERAL SOLAR ENERGY RESEARCH AND DEVELOPMENT

STAFF REPORT

TO THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

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LETTER OF TRANSMITTAL

House of Representatives,
Committee on Science and Technology,
Washington, D.C., July 19, 1983.

To All Members, Committee on Science and Technology:

I am herewith transmitting a report prepared by Dr. Eugene Frankel of the Committee staff. The report, entitled "A Multi-Year Framework for Federal Solar Energy Research and Development," is an in-depth review of solar energy R&D, its past, present, and future.

The report recommends a federal program for solar energy R&D which is clearly more ambitious than that proposed by the present Administration, but which is philosophically consistent with Congressional intent as expressed in recent authorizing and appropriations legislation.

I believe this excellent report should promote useful discussions on the future of solar energy and the appropriate federal role. I commend it to my colleagues.

Sincerely,

Don Fuqua, *Chairman.*

CONTENTS

Page

EXECUTIVE SUMMARY 1

I. BACKGROUND AND JUSTIFICATION FOR THE REPORT
  The Historic Role of Congress in Federal Solar R&D Policy, 1974-80 13
  The Reagan Era 15
  The Need for a Congressional Framework for Future Solar R&D 16

II. ASSUMPTIONS AND METHODOLOGY
  Extension of Existing Solar Tax Credits to At Least 1990 and Possible Enhancement 20
  Smoothing the Transition to the Private Sector 21
  A Re-Defined Role for the Federal Government in Energy RD&D 22

III. PHOTOVOLTAICS
  Program History 25
  Recent Budget Changes 28
  Recommendations for a Multi-Year Photovoltaics Program 29

IV. SOLAR THERMAL ENERGY SYSTEMS
  Program History 37
  Recent Budget History 40
  Recommendations for a Multi-Year STES Budget 41

V. SOLAR BUILDINGS ENERGY RESEARCH
  Active Systems 49
    Program History 49
    Recommendations 52
  Passive Systems 54
    Program History 54
    Recommendations 56

VI. BIOMASS AND ALCOHOL FUELS
  Program History 59
  Recommendations 62

VII. WIND SYSTEMS PROGRAM
  Program History 67
  Future Directions 69

VIII. OCEAN THERMAL ENERGY SYSTEMS
  Program History 73
  Current and Future Activities 74

EXECUTIVE SUMMARY

THE HISTORIC ROLE OF CONGRESS IN FEDERAL SOLAR RD&D POLICY, 1974–1980

In 1974, following the OPEC oil embargo, Congress acted vigorously and immediately to create a strong federal solar energy research development and demonstration program. Two major pieces of solar energy research legislation were enacted that year: The Solar Heating and Cooling Demonstration Act of 1974 (Public Law 93-409) and the Solar Energy Research, Development and Demonstration Act of 1974 (Public Law 93-473).

The House Science and Technology Committee (known as the "Committee on Science and Astronautics" at the time) initiated both pieces of legislation and played an active role in securing their passage.

The legislation was quite specific in the role it envisaged for the Federal Government in solar energy: It required the Federal Government to:

> (1) Pursue a vigorous and viable program of research and resource assessment of solar energy as a major source of energy for our national needs; and
>
> (2) Provide for the development and demonstration of practicable means to employ solar energy on a commercial scale (Public Law 93-473).

In subsequent years, Congress continued to reaffirm its commitment to a strong federal solar research, development and demonstration program aimed at establishing the near-term viability of a variety of solar technologies (including solar heating and cooling, photovoltaics, solar thermal power systems, biomass and alcohol fuel technologies, wind energy conversion systems, ocean energy systems, solar ponds and others). The "Solar Photovoltaic Energy Research, Development and Demonstration Act of 1978" (Public Law 95-590) declared it to be:

> The policy of the United States . . . to establish during the next decade an aggressive research, development and demonstration program involving solar photovoltaic energy systems . . .

The "Wind Energy Systems Act of 1980" (Public Law 96-345) mandated:

> An aggressive research, development, demonstration and technology applications program for converting wind energy into electricity and mechanical energy . . .

The Ocean Thermal Energy Conversion Research Development and Demonstration Act (Public Law 96-310), required DOE to construct at least two OTEC pilot plants of total capacity of at least 100MW by 1986.

Under this ambitious legislative agenda, and with annual infusions of new funds from Congress, the federal solar RD&D budget grew rapidly. In 1974, it was less than $14 million; by 1977, it had increased, by a factor of 20, to $280 million; by 1980, it had doubled again, to more than $570 million.

The Reagan era

The Reagan Administration proposed a strongly revised role for the Federal Government in solar energy. It decided to:

> Shift the focus of the Department of Energy's solar activities away from costly near-term development, demonstration and commercialization efforts and into longer-range research and development projects that are too risky for private firms to undertake.
>
> It will be the free marketplace—and not goverment—which will be expected to supply the considerable capital investments required to support the commercial introduction of new and alternative energy technologies into the marketplace.

Accompanying this revised federal role was a substantially reduced federal budget for solar energy. The fiscal year 1982 Reagan budget request for solar energy was $193 million, a cut of 65 percent. The fiscal year 1983 budget request was $72.3 million, a further 70 percent reduction in solar R&D funding.

Congress, however, has been unwilling to accept fully the Administration's plan to limit all federal involvement in solar energy RD&D to basic research. In the fiscal year 1982 Energy and Water Appropriations Bill, Congress increased the Administration's solar R&D request by 40 percent, to $268 million, and redirected a sizeable fraction of the solar program toward near term technology development and demonstration. The fiscal year 1983 Continuing Resolution funded the solar programs at about $202 million which is an increase of nearly 200 percent over the Administration's request.

For fiscal year 1984 the Administration has proposed $86.9 million for solar energy, but the House has authorized $204.5 million and appropriated $178 million.

The need for a congressional framework for future solar research and development

Federal solar policymaking has reached something of an impasse. Funding for solar RD&D has been reduced to the point where the ambitious goals embodied in the solar legislation of the 1970's cannot be met. However, Congress has not been convinced that "long-term, high risk, high-payoff research" is the only activity deserving of government funding or that the federal solar programs should be terminated or limited to laboratory effort.

In order to help resolve that impasse it is essential for Congress to provide its own policy and budgetary framework for solar energy research and development over the next few years. The purpose of this report is to provide such a framework from the point of view of the lead committee in authorizing solar energy R&D programs—the House Science and Technology Committee.

Policy framework

The proposed Congressional policy framework for solar enrgy research and development is composed of four elements:

1. *Level funding for federal solar research and development programs to insure continuity and stability.*—The DOE Energy Research Advisory Board pointed out, in its report, "Solar Energy Research and Development: Federal and Private Sector Roles" (September, 1982) that:

> Continuity in federal actions is essential to solar R&D, as it is to all R&D . . . Rapid changes and discontinuities in federal policy and program direction over the last five years have been disruptive to orderly technical progress and have caused uncertainties and unanticipated costs in the private sector.

To provide for continuity and stability of planning Committee staff recommends a level-funded solar energy research and development program at approximately the following levels:

	Millions
Photovoltaics	$65
Solar Thermal Energy Systems	50
Solar Building Energy Research	25
Biomass and Alcohol Fuels	30
Wind Energy Conversion (technology base)	20
Ocean Energy Systems (technology base)	10
Information and International Activities	5
Program Direction	5
Total	210

2. *Extension of existing solar business tax credits to 1990, and possible enhancement.*—The Energy Development and Applications Subcommittee has received overwhelming support for the solar business tax credits. At the fiscal year 1983 DOE Authorization hearings and also at a special oversight hearing on "Business Tax Incentives for Renewable Energy Technologies" on July 13, 1982, witnesses consistently cited and beneficial role of the tax credits in assuring the market needed to stimulate private sector RD&D. They unanimously recommended extending the tax credits past their expiration data of 1985 and in some cases increasing them by as much as 10 percent. As a result of this testimony, in February 1983, Chairman Don Fuqua (D-Fla.) and Ranking Minority member Manuel Lujan (R-NM) introduced H.R. 1775, extending the solar business tax credit to 1990, and increasing their value to 25 percent. Identical provisons are contained in more general solar tax credit legislation introduced by Mr. Packwood in the Senate (S. 1305) and by Mr. Heftel in the House (H.R. 3072).

3. *Better cooperation between government and industry to smooth the transition to the private sector.*—The private sector does not appear to have been able to increase its R&D activities by a sufficient amount to compensate for the substantial reductions in Federal solar programs. In some areas, in fact, private sector funding appears to have actually decreased. This may be due to the "precarious competitive position" of the solar industry "vis-a-vis conventional energy technologies and older industries that are firmly established." (ERAB Solar R&D Report.) To smooth the transition to the private sector three conditions must be met;

(a) The Federal Government must work closely with industry in defining public and private sector roles in planning the transition.

(b) Termination of federal involvement must take place in an orderly, gradual fashion, which allows the private sector to gear up its own activities in response.

(c) Development and demonstration activities which are initiated by mutual agreement between DOE and industry should be continued until a logical termination point is reached.

4. *A re-defined role for the Federal Government in energy research and development.*—Energy RD&D has traditionally been defined as consisting of seven separate but somewhat overlapping activities:

> Basic Research; Applied Reseach; Exploratory Development; Technology Development; Systems Testing; and Commercialization.

The Reagan Administration would cut off federal assistance for most activities occurring beyong the "applied research" phase. The solar legislation of the 1970's on the other hand, envisaged a strong federal presence through the commercialization phase.

A compromise position on the federal role in solar energy RD&D, which preserves existing technology development efforts, but is not as expensive or intrusive into the marketplace as the historic congressional solar program, might consist of the following:

Technology development through the prototype, process development unit or pilot plant stage, would continue to be considered a federal responsibility. Private sector cost-sharing to insure on-going interest beyond the prototype stage is desirable, but cannot be expected to exceed 25 percent.

Engineering development and systems testing would be primarily the responsibility of the supplier industry, but with some federal assistance. Provision would be made for the Federal Government to reduce its involvement in new technologies gradually rather than all at once and to assume some of the still-significant risk involved in scale-up, mass production and testing in a user environment. Support would be in the form of cost-shared grants and cooperative agreements with provisions for the government to recoup its investment if the technology proves successful.

Commercialization would be considered a purely private sector activity, with federal assistance limited to tax credits provided for specific policy purposes such as to compensate for tax advantages given to conventional fuels or to assist an infant energy industry until it can assure a mature, reliable, cost-effective product.

Budgetary framework

The proposed congressional budgetary framework consists of the following mutiyear budgets for each of the primary solar technology programs: photovoltaics; solar thermal energy systems; solar building energy research; biomass and alcohol fuels; wind energy systems and ocean thermal energy systems.

Photovoltaics

Staff recommends the restoration of a balanced photovoltaics RD&D program at $65 million per year for the next 5 years. Advanced Research and Development and Technology Development should each receive 45 percent of the budget; Tests and Applications and Systems Engineering and Standards should split the remaining 10 percent. Market Development activities will be left to the private sector.

The photovoltaic program at the $65 million per year level would consist of the following activities:

1. Advanced R&D on photovoltaic cell materials and devices, including thin-film amorphous and crystalline materials, polycrystalline silicon physics, advanced concentrator cell concepts, cell optimization, and fundamental process research on junction formation and metalization.
2. Technology Development:
    (a) Flat plate collector research and development, including module engineering, process research, cell encapsulation materials, insulation materials for high voltage modules, reliability/durability testing and analysis.
    (b) Concentrator collector research and development, including module engineering, process research, Fresnel lens development, reliability and durability testing and analysis.
    (c) Silicon material and silicon ribbon technology development.
3. Systems Engineering and Standards including technical support to industry standards groups, assessment of current system design and performance requirements to provide basis for future program direction, and balance of systems research and development.
4. Tests and Applications including operation of Residential Experiment Stations and existing experimental photovoltaic residences, operation of existing medium size systems, including PRDA's, operation of existing Data Reduction Center and continued programmatic support of grant projects.

Solar thermal

Staff recommendations for a multi-year Solar Thermal Energy Systems program are organized around two primary activities:

1. The orderly phaseout of existing technology development programs based upon the state of the technology and the ability of the supplier and user industries to carry out needed development, demonstration and testing activities.
2. Restoration of a healthy Research and Advanced Development program at fiscal year 1981 levels including work on materials, components, sunfuels, and support to the university and users communities.

These two activities can be covered by a budget that starts (in 1984) at $50 million for fiscal year 1983 and gradually decreases to $40 million by 1987.

Central receivers

The central receiver technology has reached the engineering development-commercial demonstration phase in which private industry must assume the primary burden for developing the technology. However, there are a number of areas in which federal support is needed to enable industry to complete the transition. Most important of these is completion of the test program for Solar One as orginally provided for in the contract between the Department of Energy and Southern California Edison.

A second crucial activity is support for the development and testing of advanced components such as receivers, steam generators and storage. A third area is in continued operation of existing test facilities. The last federal support area related to central receiver technology concerns the repowering demonstration.

The solar industry has proposed that DOE fund detailed design of one electricity and one industrial process heat repowering application to narrow cost uncertainties to the plus or minus ten percent range. Since this involves a federal investment of about $15 million, instead of the $250 million or more originally envisaged for repowering demonstrations, it appears to be a prudent step for the Federal Government to take in order to insure its $300 million investment in this technology.

Parabolic trough

Parabolic trough systems are being commercialized by industry. The only federal role is to conduct generic research on materials and components—such as selective coatings, reflective surfaces, adhesives, advanced receivers.

Parabolic dish

Consistent with the general principle set forth in chapter one of this report that federal support should continue for technology development of promising solar energy systems, the existing dish program should be completed. That means developing and testing two generations of complete Stirling and Brayton cycle modules; carrying out research and development on advanced concentrators, receivers, control systems and storage concepts and cost-sharing on multi-unit tests in a user environment for both Stirling and Brayton systems.

Hemispherical bowl

Despite vigorous promotion by its developers, this technology has not received independent support from industry or the analytical community. This lack of broad support for bowl technology makes it difficult to recommend further funding. DOE should do a complete, independent assessment of the potential and technical problems facing bowl technology, with the goal of determining whether further support in the form of modest component development contracts or small systems tests is warranted in the fiscal year 1985–86 time frame.

Solar pond

The first need for this program is to establish a single program office at DOE headquarters and a single multi-year research and development plan that is agreed to by the entire solar pond community. The second is to determine what kind, if any, of large experimental facility is needed to resolve the technical and economic issues that cannot be addressed with existing small pond test facilities.

Third, a decision appears needed on which end use the program should address for early systems tests and applications. There appears to be consensus among experts that further research would be useful on topics such as thickness and maintenance of the convecting and nonconvecting zones; pond transmissivity; heat loss to the ground; heat extraction; heat rejection and wind effects. Thus a $2 million a year basic research and development program for solar ponds appears warranted.

Restoration of a healthy research and advanced development program

Review of the considerable testimony and literature in the field supports a long-term Research and Advanced Development (RAD) program at the historic budget level of $20 million a year. This program would include research and exploratory development on materials, components, process for making fuels and chemicals and support to the university and industrial user communities.

TABLE 4-2.—RECOMMENDED BUDGET FOR STES, FISCAL YEARS 1984-87

[By fiscal year, in millions of dollars]

	1984	1985	1986	1987
Central receivers:				
Barstow completion and operation	4.0	3.2	3.0	
Repowering	8.0	4.0		
CRTF operation	2.0	1.0	1.0	
Component development and testing	6.8	5.5	5.0	
Subtotal	20.8	13.7	9.0	
Parabolic dish:				
Small community S.E.	3.0	3.0	3.0	3.0
Baryton module development	4.0	3.5	2.5	0.5
Concentrator development	2.5	3.5	2.5	2.0
Stirling (tests and second generation)	3.8	1.8	1.1	1.0
PDTS operation	1.0	1.0	1.0	1.0
Applied research and receiver development	2.0	1.0	2.0	2.0
Subtotal	16.3	14.8	12.1	9.5
Solar pond RD&D	2.0	2.0	2.0	2.0
Research and advanced development:				
Materials R&D	4.0	4.0	5.0	7.0
Components R&D	2.2	4.6	5.1	6.4
Sunfuels	2.0	3.7	6.8	8.4
Advanced development	2.0	2.0	2.0	2.0
Subtotal	10.2	15.3	18.9	25.8
Planning and assessment	2.0	2.0	1.0	1.0
Total	51.3	47.8	43.0	38.3

Solar buildings energy research

Active systems

A substantial amount of long term, high risk R&D, which will improve the cost and performance characteristics of active solar systems and not duplicate private sector efforts, remains to be done. This is true for all three program areas: materials and components R&D, technology development, and systems tests and evaluations.

This recommended research and development could be carried out within a budget of $10 million a year over the next four years. A proposed budget for active solar heating and cooling R&D is presented below.

TABLE 5-3.—PROPOSED BUDGET FOR ACTIVE SOLAR HEATING AND COOLING R&D

[By fisac year, in millions of dollars]

	1984	1985	1986	1987
Material and components R&D:				
Collector materials	1.5	1.5	1.5	1.5
Desiccant materials	1.5	1.5	1.0	1.0
Advanced collector R&D	1.0	1.0	1.0	1.0
Storage	0.5	0.5	0.5	0.5
Subtotal	4.5	4.5	4.0	4.0
Technology development—Chillers:				
Absorption	1.0	1.0	1.0	1.0
Desiccant	1.0	1.0	1.0	1.0
Subtotal	2.0	2.0	2.0	2.0
Systems tests and evaluation:				
Systems tests (and procedures development)	1.5	1.5	1.5	1.5
Systems analysis	1.5	1.5	1.5	1.5
Performance monitoring	1.0	1.0	1.0	1.0
Subtotal	4.0	4.0	4.0	4.0
Total active solar	10.5	10.5	10.0	10.0

Passive systems

A workshop on Building Energy Research co-sponsored by DOE, the House Committee on Science and Technology, EPRI, GRI, AIA, NAHB/RF and ASHRAE was held on January 12-14, 1983. Its recommendations describe a potential research agenda for passive solar systems, in coordination with an overall building energy research program. Based on that workshop, and on testimony to the EDA Subcommittee and internal planning documents prepared by and for DOE, staff recommends a $15 million/year passive solar budget oriented around six primary activities. These are materials R&D; heat transfer research; performance monitoring and evaluation; modeling and systems analysis; daylighting simulation and analysis; and passive cooling.

A recommended multi-year budget for these activities is provided below.

TABLE 5-5.—PROPOSED BUDGET FOR PASSIVE SOLAR R&D

[By fiscal year, in millions of dollars]

	1984	1985	1986	1987
Materials R&D:				
Aperture materials	2.5	2.5	2.5	2.5
Storage materials	7.5	2.0	2.0	2.0
Heat transfer materials	1.5	1.5	1.0	0.5

TABLE 5-5.—PROPOSED BUDGET FOR PASSIVE SOLAR R&D—Continued

[By fiscal year, in millions of dollars]

	1984	1985	1986	1987
Subtotal	6.0	5.5	5.5	5.0
Heat transfer research	2.0	1.5	1.0	0.5
Performance monitoring and evaluation:				
Component testing	1.3	1.3	1.3	1.3
Systems validation	1.7	1.7	1.5	1.0
Performance monitoring	1.0	1.0	1.0	1.0
Subtotal	4.0	4.0	3.8	3.3
Systems analysis and models	1.3	1.3	1.3	1.3
Daylighting	1.0	1.0	1.0	1.0
Passive cooling	1.5	1.5	1.5	1.5
Total passive solar	15.8	14.8	14.1	12.6

Biomass and alcohol fuels

The magnitude of the potential contribution of energy from biomass feedstocks to the Nation's economy is great enough to justify a continued Federal research and technology development effort in both production and conversion processes. A continuation of both the Biomass and the Alcohol Fuels programs at fiscal year 1982 funding levels with the same mix of program activities would be a prudent and cost-effective Federal investment which would not duplicate efforts of the private sector. In particular, the woody and herbaceous crop R&D programs should be continued through the pilot planting phase, and a modest technology development and testing program for innovative waste and residue harvesting equipment should be initiated.

In the conversion area, technology development efforts should be continued through the pilot plant stage for medium-BTU gasification systems, and should be initiated for liquefaction, pyrolysis, anaerobic digestion and biological production of hydrogen when laboratory results have identified a potentially attractive process. A recommended budget for the overall biomass energy technology program for fiscal year 1984 is presented below. It is believed that all activities should continue through fiscal year 1987 within the same overall budget level, but with changes in emphasis to reflect developments within each of the technology areas.

Table 6-2.—A recommended for biomass and alcohol fuels, fiscal year 1984

	Millions
Feedstock production process R&D:	
Short rotation woody crops	$4.0
Aquatic species	2.5
Herbaceous crops	3.0
Harvesting techniques	1.0
Subtotal	10.5
Conversion technology R&D:	
Biochemical conversion (including anaerobic digestion and pre-treatment	6.8
Thermochemical conversion (including gasification, liquefaction and pyrolysis	8.6
Biological hydrogen production	1.5

Supporting research	2.0
Subtotal	18.9
Total Biomass	29.4

Wind

The goal of the DOE large wind turbine program has been to develop a machine that is competitive with conventional energy systems at a wide variety of sites in moderate to good wind regimes. To insure that program goals are met, and that the federal investment of more than $130 million in large machine technology is realized, it is essential that the MOD-5 program be completed through the fabrication and testing of both the MOD-5A and the MOD-5B.

Once the MOD-5 program is completed the federal program can terminate its engineering development activities and focus on aerodynamic and structural research to support industry. NASA Lewis should continue its role as lead national laboratory for horizontal axis machine R&D and Sandia should retain management of vertical axis R&D activities. Component development and testing to support new approaches to lowering costs or improving performance should be initiated when requested by industry, with industry cost-sharing. Test facilities and machines should be maintained to carry out these activities.

Continued operation of the Rocky Flats test center for small wind machines needs to be reassessed. The facility is expensive to operate and has a highly erratic wind regime, varying from little or no wind over much of the year to very high winds with destructive cross-currents. Moreover, it is not clear that the small wind industry desires to support such a facility on a continuing basis.

TABLE 7-3.—PROPOSED WIND SYSTEMS BUDGET FOR FISCAL YEAR 1984-87

[In millions of dollars]

	1984	1985	1986	1987
Aerodynamics research	3.6	4.0	4.0	2.0
Structural research	3.5	4.0	4.0	2.0
Small wind test center	1.5	1.0		
Completion of MOD-5	14.0	10.0	4.0	
Design and testing of advanced intermediate machine			2.0	8.0
Resource assessment			2.0	2.0
Total	22.6	19.0	16.0	14.0

Ocean thermal energy systems

With funding of the preliminary design for at least one OTEC pilot plant, and associated hardware-related research and development, the closed-cycle program can come to a logical termination point in fiscal year 1983. However, there appears to be a potential for lowering the cost and improving the efficiency of OTEC systems by moving to advanced power conversion concepts. One such concept, the open-cycle system, in which sea water is allowed to evaporate and drive a turbine directly, appears especially promising. It is recommended that DOE begin a multi-year program on open-cycle OTEC and other advanced conversion concepts.

The following five year program is proposed:

1. Continue the development of the Seacoast Test Facility (STF) to provide a base for a 1 MW size test of the open cycle.
2. Design and build a 1 MW size experimental open cycle system to be installed and tested at STF.
3. Conduct continued research on thermal cycles applicable to low temperature difference sources with the goal of reducing costs in a variety of applications.

TABLE 8-2.—PROPOSED OTEC BUDGET FOR FISCAL YEARS 1984-87

[In millions of dollars]

	1984	1985	1986	1987
Prepare seacoast test facility by installing seawater pipes and pumps for a 1 MW size experiment	2.0	1.0		
Operate seacoast test facility		1.0	1.5	1.5
1 MW open cycle system design, build and test	5.0	5.0	3.0	1.0
Conduct research on thermal cycles applied to low temperature difference sources	1.0	2.0	2.0	2.0
Total	8.0	9.0	6.5	4.5

CHAPTER I.—BACKGROUND AND JUSTIFICATION FOR THIS REPORT

The Historic Role of Congress in Federal Solar RD&D Policy, 1974–80

In 1974, following the OPEC oil embargo, Congress acted vigorously and immediately to create a strong federal non-nuclear energy research development and demonstration program. Six major pieces of energy research legislation were enacted that year:

> The Federal Non-Nuclear Energy Research and Development Act of 1974 (Public Law 93–577).
>
> The Solar Heating and Cooling Demonstration Act of 1974 (Public Law 93–409).
>
> The Solar Energy Research, Development and Demonstration Act of 1974 (Public Law 93–473).
>
> The Geothermal Energy Research, Development and Demonstration Act of 1974 (Public Law 93–410).
>
> The Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1974 (Public Law 93–413).
>
> The Energy Reorganization Act of 1974 (Public Law 93–438).

Two of those, Public Law 93–409 and Public Law 93–473, were directed specifically at solar energy. Two others, Public Law 93–438 and Public Law 93–577, mentioned solar energy explicitly as requiring expanded federal attention. The House Science and Technology Committee (known as the "Committee on Science and Astronautics" at the time) initiated much of this legislation and played an active role in securing its passage.

The legislation was quite specific in the role it envisaged for the Federal Government in solar energy. The Solar Energy Research, Development and Demonstration Act, for example, declared it the policy of the Federal Government to:

> (1) Pursue a vigorous and viable program of research and resource assessment of solar energy as a major source of energy for our national needs; and
>
> (2) Provide for the development and demonstration of practicable means to employ solar energy on a commercial scale (Public Law 93–473).

The "Solar Heating and Cooling Demonstration Act" was equally explicit:

> It is therefore declared to be the policy of the United States and the purpose of this Act to provide for the demonstration within a three-year period of the practical use of solar heating technology and to provide for the development and demonstration within a five-year period of the practical use of combined heating and cooling technology.

In subsequent years, Congress continued to reaffirm its commitment to a strong federal solar research, development and demonstration program aimed at establishing the near-term viability of a variety of solar technologies (including solar heating and cooling, photovoltaics, solar thermal power systems, biomass and alcohol fuel technologies, wind energy conversion systems, ocean energy systems, solar ponds and others). In the Department of Energy Organization Act of 1977 (Public Law 95-91), Congress declared as a purpose of that Act:

> To place major emphasis on the development and commercialization of solar, geothermal, recycling and other technologies utilizing renewable energy resources.

The "Solar Photovoltaic Energy Research, Development and Demonstration Act of 1978" (Public Law 95-590) declared it to be:

> The policy of the United States . . . to establish during the next decade an aggressive research, development and demonstration program involving solar photovoltaic energy systems . . . (with) the objectives . . . (1) to double the production of solar photovoltaic energy systems each year . . . (2) to reduce the average cost of installed photovoltaic energy systems to $1 per peak watt by 1988. (3) to stimulate the purchase by private buyers of at least 90 per centum of all solar photovoltaic energy systems produced in the U.S. during fiscal year 1988.

Similarly, in the "Wind Energy Systems Act of 1980" (Public Law 96-345) Congress mandated:

> An aggressive research, development, demonstration and technology applications program for converting wind energy into electricity and mechanical energy . . .

and found that—

> It is the proper and appropriate role for the Federal Government to undertake research and development, to participate in demonstration programs for wind energy systems and assist private industry, other entities, and the general public in hastening the widespread utilization of such systems.

That same year Congress passed an Ocean Thermal Energy Conversion Research Development and Demonstration Act (Public Law 96-310), which required DOE to construct at least two OTEC pilot plants of total capacity of at least 100MW by 1986.

Each of these pieces of solar energy research and development legislation was enacted by overwhelming majorities in Congress, at the initiation of the Science Committee.

Under this ambitious legislative agenda, and with annual infusions of new funds from Congress, the federal solar RD&D budget grew rapidly. In 1974, it was less than $14 million; by 1977, it had increased, by a factor of 20, to $280 million; by 1980, it had doubled again, to more than $570 million.

Table 1 below illustrates the dramatic growth in federal solar energy RD&D expenditures between fiscal year 1974 and fiscal year 1981.

TABLE 1.—SOLAR ENERGY R&D BUDGET HISTORY (U.S. ERDA & DOE)

[Budget authority in thousands, by fiscal year]

Program	1975	1976	Transfer quarter	1977	1978	1979	1980	1981	1982	Requested 1983
Solar heating and cooling	$13,600	$43,710	$11,500	$113.636	$221,800	$89,700	$84,850	$68,600	$22,100	0
Solar thermal	13,200	20,600	5,550	69,517	104,100	117,200	143,200	120,020	55,950	$18,025
Photovoltaics	5,200	21,559	6,500	54,898	63,500	120,000	150,045	133,200	74,000	27,035
Wind	5,700	14,403	4,500	22,447	36,700	59,555	60,555	54,200	34,400	5,485
Ocean	1,900	6,100	2,400	13,620	36,000	41,145	43,000	34.600	20,800	0
Biomass	900	5,140	1,920	9,532	21,186	42,400	33,000	27,200	20,500	6,605
Alcohol fuels	0	0	09	0	0	0	22,000	18,000	10,000	2,940
Other	1,400	3,338	1,400	0	10,205	44,222	34,515	27,026	30,474	12,146
Total solar energy	41,900	114,850	33,770	283,650	393,491	514,222	571,165	482,846	268,224	72,236

THE REAGAN ERA

The Reagan Administration has proposed a strongly revised role for the Federal Government in solar energy. On February 18, 1981, in the President's "Program for Economic Recovery," the Administration announced its intention to:

> Shift the focus of the Department of Energy's solar activities away from costly near-term development, demonstration and commercialization efforts and into longer-range research and development projects that are too risky for private firms to undertake.
>
> The Administration will continue direct government support for solar programs focused on advanced research concepts and exploratory development, but assumes that the private sector will be responsible for developing marketable systems once technical feasibility is established.

Accompanying this revised federal role was a substantially reduced federal budget for solar energy. The Administration proposed to cut $93 million from ongoing fiscal year 1981 activities (initially budgeted at close to $600 million) and to reduce the original fiscal year 1982 request from $579 million to $193 million. (A cut of more than 65 percent). In its fiscal year 1983 budget request, the Administration proposed a further 70 percent reduction in solar R&D funding to $72.3 million. In addition, the Administration considered eliminating the solar business tax credits.

Congress, however, has not accepted the Administration's attempt to limit federal involvement in solar energy RD&D to basic and applied research and exploratory development. In the fiscal year 1982 Energy and Water Appropriations Bill, Congress increased the Administration's solar R&D request by 40 percent and redirected a sizeable fraction of the solar program toward near term technology development and demonstration. The fiscal year 1983 request was increased by more than 250 percent, with many projects included which do not conform to the Administration's guidelines of "long term, high risk, high payoff." The House Appropriations Committee, in its report accompanying a $180.4 million appropriation for solar energy R&D in fiscal year 1983, stated its views as follows:

> The Committee agrees, to an extent, that the marketplace must ultimately decide what practical role the solar and renewables will assume in displacing more traditional sources of energy. The Committee also agrees that some basis must be established to assist in determining the conditions under which federal R&D assistance will be provided. The Committee does not agree, however, that most solar and renewables research has been brought to the point where the private sector is willing to commit to it.
>
> Because of this, the Committee considers it essential that a viable solar and renewable energy research and development program be maintained in the Department of Energy. . . . Funding is provided to continue to complete several major demonstration projects and to projects and to collect data and information from ongoing programs so that the federal investment is not lost.

The fiscal year 1983 Continuing Resolution funds the solar program at about $202 million. The fiscal year 1984 appropriation, signed by the President July 14, provides $178 million. Details are presented in the table below.

THE NEED FOR A CONGRESSIONAL FRAMEWORK FOR FUTURE SOLAR RESEARCH AND DEVELOPMENT

Federal solar policymaking has reached something of an impasse. Federal funding for solar RD&D has been reduced to the point where the ambitious goals embodied in the solar legislation of the 1970's cannot be met. However, Congress has not been convinced that "long-term, high-risk, high-payoff research" is the principal activity deserving of government funding or that some federal solar programs such as passive solar and OTEC should be discontinued.

The continuing disagreement between Congress and the Administration over funding levels and philosophy poses severe problems for R&D program managers. Each year they have to wait until a continuing resolution or an appropriations bill has been passed—often several months into the new fiscal year—before they can determine the scope and magnitude of their programs. They cannot make intelligent plans for the following year's activities; they do not know whether to reduce staffing levels or hold them constant; they cannot initiate projects that may require funding over a multi-year period. The resulting effort that emerges is not a logical and well-reasoned R&D activity.

Research and development programs require continuity in funding, personnel and program direction in order to be successful. As the Solar Panel of the Energy Research Advisory Board noted in its report on solar research and development:

> Continuity in federal actions is essential to solar R&D, as it is to all R&D. . . . Rapid changes and discontinuities in federal policy and program direction over the last five years have been disruptive to orderly technical progress and have caused uncertainties and unanticipated costs in the private sector. To stabilize DOE and Laboratory planning and program execu-

tion, the Panel urges the Office of Management and Budget to support rolling 2-year appropriations by Congress for solar R&D, with carry over funding.

In order to insure that federal research and development programs make reasonable use of taxpayer dollars, and that DOE and national laboratory program managers can plan for the future, it is essential for policy-makers to provide realistic guidance as to likely out-year funding levels. The annual appropriations process makes it difficult to commit firmly to out-year funding levels, but a multi-year budget framework prepared by an authorizing committee could help research program managers "bound the problem."

The House Committee on Science and Technology, as the authorizing Committee that initiated and has consistently supported the DOE solar R&D programs, would be a logical body to formulate a multi-year R&D framework for solar energy, which could serve as informal guidance as to the likely intent of Congress over the next few years. It would also be a vehicle for thought and discussion among concerned individuals in the public and private sectors, in the research, academic, public interest, and technology development and marketing communities. It is in this spirit that the recommendations contained in this report have been prepared.

TABLE 1-2.—SOLAR BUDGETS, FISCAL YEAR 1983 AND FISCAL YEAR 1984

[By fiscal year, in thousands]

Program	1983 appropriation	1984 administration request	1984 appropriation
Solar building energy systems	$11,650	$8,375	$17,200
Photovoltaic energy systems	58,035	32,700	51,200
Solar thermal energy systems	49,500	13,575	41,500
Biomass and alcohol energy systems	21,000	17,300	29,000
Wind energy systems	31,400	8,600	26,500
Ocean energy systems	10,500		7,000
International solar energy program	10,000		1,000
Solar technology transfer	3,000	3,100	3,250
Program support	1,000		1,000
Program direction	5,850	3,009	6,000
General reduction			−5,000
Total, solar energy	201,935	86,659	178,650

CHAPTER II.—ASSUMPTIONS AND METHODOLOGY

This report was prepared from information provided by three princial sources:

1. Testimony and transcripts from EDA Subcommittee hearings in 1981 and 1982.
2. Reports and planning documents prepared by DOE program offices, national laboratories and private industry for the DOE solar research and development programs over the past two years.
3. Discussions with industry officials and R&D program managers at the Solar Energy Research Institute, the Jet Propulsion Laboratory, Sandia National Laboratory and Lawrence Berkeley Laboratory during site visits throughout fiscal year 1982.

It is therefore more a synthesis of expert opinion in the field than an original document. A cost-benefit analysis of alternative solar RD&D investments has not been attempted; a market penetration study for the year 2000 has not been performed. Rather, the existing solar R&D programs have been examined, and promising avenues for future research and development have been identified.

As a result of this approach, the report is structured around the existing solar technology programs: photovoltaics, solar thermal energy systems, solar building energy research, biomass and alcohol fuels, wind energy conversion systems and ocean energy systems. The first and longest chapters are devoted to photovoltaics and solar thermal energy because these are the largest current solar programs and appear to require the greatest amount of future support. Solar heating and cooling and biomass fuels follow. These two research areas are often undervalued because they are near-term options, but they also present a wide variety of promising research opportunties. Finally, wind and OTEC will be treated as technology base programs because their major engineering development activities will terminate in the next few years.

Estimates have been prepared of the funding requirements for each of the solar technology programs over the next four to five years. These estimates are tentative and represent best guess of the resources needed to carry out the research initiatives described in the report. A program by program breakdown is provided below:

Table 2-1.—Estimate of yearly funding requirements, fiscal years 1984–88

Program:	*Millions*
Photovoltaics	$65
Solar thermal energy systems	50
Solar building energy research	25
Biomass and alcohol fuels	30
Wind energy conversion	20
Ocean energy systems	10
Information and international activities	5
Program direction	5
Total	210

The $210 million/year estimated level is much higher than the President's fiscal year 1984 request of $86.9 million, and slightly greater than the actural fiscal year 1983 funding level for the solar programs. But it is actually less than the level originally proposed by the President in his "Economic Recovery Program" of February, 1981. At that time the Administration proposed a budget authority for solar energy R&D of $236 million in fiscal year 1983; $251 million in fiscal year 1984; $265 million in fiscal year 1985; and $278 million in fiscal year 1986. ("A Program for Economic Recovery," February 18, 1981, p. 4-17).

In addition to a level-funded budget of about $210 million a year, two additional circumstances would contribute to the ultimate success of the nation's solar R&D effort. These are the extension to 1990 and possible enhancement of the existing solar business tax credits, and better cooperation between government and industry to make the transition to the private sector as smooth as possible.

EXTENSION OF EXISTING SOLAR BUSINESS TAX CREDIT TO AT LEAST 1990, AND POSSIBLE ENHANCEMENT

At the fiscal year 1983 DOE Authorization hearings and also at a special oversight hearing on "Business Tax Incentives for Renewable Energy Technologies" on July 13, 1982, witnesses consistently cited the beneficial role of the tax credits in assuring the market needed to stimulate private sector RD&D. They recommended extending the tax credits past their expiration date of 1985 and in some cases increasing them by as much as 15 percent. As a result of this testimony on February 7, 1983, Chairman Don Fuqua (D-FL) and Rep. Manuel Lujan (R-NM) introduced H.R. 1775, extending the solar business tax credits to 1990 and increasing their value to 25 percent.

The Solar Panel of the Energy Research Advisory Board also strongly supported solar business tax credits:

> Existing business and residential energy tax credits are essential to the near-term health of most of the solar industry because they stimulate investment by balancing existing subsidies for other energy sources. These should be extended to 1990, with a gradual phase down beginning after 1986. (p. 4)

With the curtailment of direct federal solar commercialization activities and the reduction in scope of the federal solar RD&D program, the extension of existing solar tax credits appears necessary to ensure that the federal investment in solar energy to date is not wasted. Moreover, to compensate for the "bases adjustment" provisions of the Tax Equity and Fiscal Responsibility Act of 1982, which reduce the value of solar tax credits by as much as 30 percent, a small increase in the value of the tax credits is necessary. Specifically, photovoltaics, large wind systems, solar thermal central receivers and parabolic dishes require extension of the business tax credits to 1990 to ensure third party project financing of early applications.

SMOOTHING THE TRANSITION TO THE PRIVATE SECTOR

The EDA Subcommittee has made considerable efforts to ascertain the response of the private sector to the reductions in federal solar RD&D. The results are, at best mixed. A few DOE contractors have increased their cost sharing on federally-funded development and demonstration projects such as the MOD-5 Wind Turbine; and several private sector demonstration projects have been assisted by the accelerated depreciation provisions of the Economic Recovery Tax Act of 1981 (the ARCO Solar 1 MW photovoltaics plant in Southern California is a possible example). However, several witnesses have testified that industry regards the cuts in federal funding as a signal that the solar technologies are no longer considered promising by the Government. Some firms are, in fact, apparently reducing their own efforts in solar as a response, to federal budget cuts. Dr. Marshall Alper of the Jet Propulsion Laboratory offered the following description of that trend:

> It has been JPL's experience that the funding cutbacks in JPL sponsored silicon R&D have led to: (1) a significant decrease of corporate silicon R&D funding at most (but not all) contractors, (2) a reduction in risk taken by the silicon photovoltaic industry and (3) an increased inhibition to the flow of R&D information as complete, privately funded development increases.

The ERAB Solar panel report notes the following characteristics of the U.S. solar industry:

> * * * The United States solar industry is in a precarious competitive position vis-a-vis conventional energy technologies and older industries that are firmly established. In addition to the technical risks associated with relatively new technologies, the emerging solar industry has to contend, conditions, including high cost of capital and fluctuating energy demand and prices, as well as uncertainty about federal tax and regulatory policy—all of which serve to increase the perception of risk and to discourage investment.

For the transfer of responsibilities to the private sector envisaged in a reduced federal R&D effort to work effectively, it appears that at least three conditions must be fulfilled:

1. The Federal Government must work closely with industry in defining public and private sector roles and in planning the transition.
2. Termination of federal involvement must take place in an orderly, gradual fashion, rather than abruptly in the course of a singleyear. This allows the private sector time to gear up its own activities in response.
3. Development and demonstration activities which were initiated by mutual agreement between DOE and industry should be continued until a logical termination point is reached, rather than ended as rapidly as possible for budgetary reasons.

Although DOE program managers have tried to effect a more orderly transition to the private sector, they have often been thwarted in their efforts by budget decisions that do not recognize the needs of industry. Commitment to the three principles enunciated above would ensure an orderly transition to the private sector.

A RE-DEFINED ROLE FOR THE FEDERAL GOVERNMENT IN ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION

In order to select those activities deserving of federal support, as opposed to those that could be delegated to the private sector, a set of criteria for federal involvement in R&D projects and programs has been developed. These criteria are, of necessity, more restrictive than the "demonstrate and commercialize" philosophy that often guided Congressional mandates to the Administration in the 1970's. Yet, they are also more inclusive than the "do only research and some exploratory development" philosophy of the present Administration. To assist the Congress in formulating its own principles for funding energy-related research and development projects in the 1980's, these criteria are discussed at some length below.

Research, development and demonstration in the energy field has traditionally been defined as consisting of seven separate but somewhat overlapping activities. These are:

1. *Basic Research.*—In which the fundamental properties of various energy-related materials and physical, chemical or biological processes are investigated for the purpose of improving scientific understanding, with minimal regard for ultimate application.
2. *Applied Research.*—Investigation of materials, processes, markets, policies and other factors which could influence the development or application of particular types of technologies.
3. *Exploratory Development.*—Laboratory scale tests of innovative processes or products for converting energy from one form to another.
4. *Technology Development.*—The development of prototypes of different promising energy technologies. Properly speaking, technology development consists of several mutually reinforcing subactivities:
    (a) *Systems Definition.*—Specification of the cost and performance of the system as a whole and various components and production processes needed to achieve a product which will be competitive in the marketplace.
    (b) *Component Development.*—Development and testing of individual components with promising cost and performance characteristics.
    (c) *Prototype Testing.*—Development and testing of completed prototypes to determine actual performance characteristics. The prototypes tested must be large enough to make meaningful projections of scale-up or mass production costs, and small enough to minimize federal exposure.
5. *Engineering Development.*—Process or product improvements on tested systems or components to reduce costs or improve performance.
6. *Systems Testing.*—Testing of large systems in a user environment to establish final cost and performance benchmarks.
7. *Commercialization.*—Tax credits, mass purchases, marketing programs and other forms of federal assistance to industry to accelerate the market penetration of commercially demonstrated technologies.

These seven activities are usually viewed as sequential, but in fact feed back on one another in an iterative process.

The Reagan Administration would cut off all federal assistance for activities occurring beyond the "applied research" phase except for some "exploratory development." The solar legislation of the 1970's, on the other hand, envisaged a strong federal presence through the commercialization phase.

Both of these extreme positions present serious problems. Government commercialization and commercial demonstration activities are expensive and can distort the workings of the marketplace. Often the choice of technology and location for a federally-sponsored demonstration is determined as much by political factors as by economic and technical considerations, leading to the demonstration or purchase of suboptimal systems. Cost overruns, delays and other inefficiencies often reduce the effectiveness of such federal activities.

Eliminating government support for technology and engineering development, on the other hand, makes it possible that the results of federal R&D will never reach the marketplace. Technology development can fail because one of the components does not achieve its cost or performance goals; because materials prove insufficiently strong or durable; because the parts do not work together well as a whole or for a large number of other reasons. Even a successful technology may still never reach the marketplace due to changes in market conditions, poor profitability or inadequate capital availability. Finally, once a technology enters the marketplace, positive cash flow occurs so many years after the start of technology development that its discounted present value may not justify the up-front expenditure to a private firm. For all of the above reasons a continued Federal role in energy technology development appears necessary.

Engineering development and systems testing involve fewer unknowns and nearer-term payback, but greater financial exposure and a great deal of risk, and uncertainty, nonetheless. Here too, a modest level of federal asistance may be justified to insure that a promising new technology receives sufficient development and testing for the private sector to assess accurately the desirability of commercialization.

The criteria for federal policy-makers to follow should be flexible and pragmatic. Are there market barriers to the new technology? Is there a national benefit that exceeds the federal costs and the private sector benefits? Is industry capable of carrying out the needed development and demonstration activities on its own? Are there subsidies to competing technologies that impede the orderly introduction of the new technology into the marketplace? Is the market for the new technology really free or is it government regulated (electricity and natural gas) or oligopolistic (oil)? Are foreign manufacturers, receiving government support for development and demonstration, likely to pose a serious threat to U.S. firms in international or even domestic markets?

With these considerations in mind, the following compromise position on the federal role in solar energy RD&D is proposed.

Technology development through the prototype, process development unit or pilot plant stage, would continue to be considered a federal responsibility. This phase involves technologies that are hand built, uneconomic, and not yet mass producible. The level of risk and length of time involved before a marketable product is available are so large that the private sector cannot be expected to fund this kind of activity on its own. Private sector cost-sharing to insure its on-going interest beyond the prototype stage is desirable but cannot be expected to exceed 25 percent. The goal of technology development should be to provide the private sector with sufficient cost and performance information to determine whether it wants to proceed to engineering development and demonstration.

Engineering development and systems testing should be primarily the responsibility of the supplier industry with some federal assistance. Provision would be made for the Federal Government to reduce its involvement in new technologies gradually rather than all at once and to assume some of the still-significant risk involved in scale-up, mass production and testing in a user environment. Support would be in the form of cost-shared grants and cooperative agreements with provisions for the government to recoup its investment if the technology proves successful. Federal cost sharing would be limited to a maximum of one half of the total costs, and test size would be restricted to the minimum required to establish reliable cost and performance estimates. For some technologies which need very large demonstrations, federal support may not be possible due to budget limitations.

Commercialization would be considered a private sector activity. Federal assistance would be limited to tax credits provided for specific policy purposes such as the following:

1. To compensate for tax advantages given to conventional fuels (such as expensing by businesses for tax purposes) which artificially reduce the economic attractiveness of alternative technologies.
2. To assist an infant energy industry until it can assure a mature, reliable, cost-effect product.
3. To capture environmental and social benefits which are not expressed in the marketplace.

In sum, the redefined federal role in solar energy RD&D would see the Federal Government as the primary agent in the development of technology prototypes, and a junior partner helping to share the risks involved in engineering development and commercial demonstration. Commercialization activities would remain in the private sector. This new federal role, combined with greater government-industry cooperation in the transition of former federal activities to the private sector; extension and possible enhancement of existing solar tax credits; and a level funded multi-year solar budget at roughly $210 million a year could provide the magnitude and stability of federal commitment required to ensure the orderly development of the solar industry over the decade of the eighties.

CHAPTER III.—PHOTOVOLTAICS

PROGRAM HISTORY

Photovoltaic devices utilize thin wafers or films of semiconducting material—such as silicon, gallium arsenide, copper indium diselenide—to convert sunlight into electricity directly, with no moving parts. The DOE Photovoltaics Program has historically had as its objective the development of "inexpensive, readily available (PV) systems that can supply safe and reliable electrical power to a wide variety of uses." (Multi-Year Program Plan, September, 1980, p. 2.) Its strategy has been:

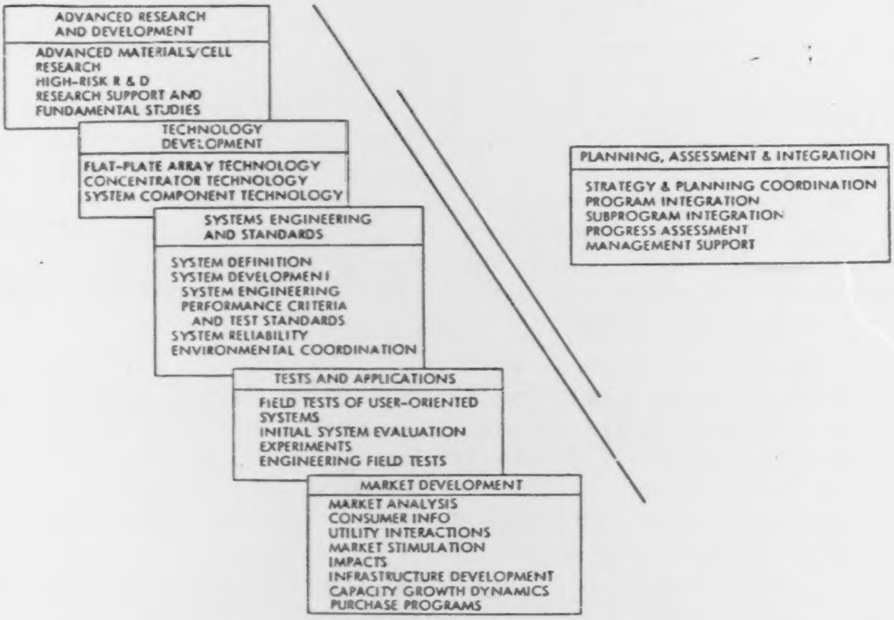
> To achieve major system cost reductions to meet the market requirements for a competitive life-cycle cost of electricity through the aggressive pursuit of advanced research, technology development, systems engineering and market development, (including) real world testing to support the accelerated transfer of technology to the marketplace (ibid., p. 3-1).

Accordingly, the Photovoltaics Program has been divided into five elements:

1. Advanced Research and Development;
2. Technology Development;
3. Systems Engineering and Standards;
4. Tests and Applications;
5. Market Development.

The program elements and their component activities are presented in the Figure below.

FIGURE: FUNCTIONS OF THE PROGRAM ELEMENTS


ADVANCED RESEARCH AND DEVELOPMENT
ADVANCED MATERIALS/CELL RESEARCH
HIGH-RISK R & D
RESEARCH SUPPORT AND FUNDAMENTAL STUDIES
TECHNOLOGY DEVELOPMENT
FLAT-PLATE ARRAY TECHNOLOGY
CONCENTRATOR TECHNOLOGY
SYSTEM COMPONENT TECHNOLOGY
SYSTEMS ENGINEERING AND STANDARDS
SYSTEM DEFINITION
SYSTEM DEVELOPMENT
SYSTEM ENGINEERING
PERFORMANCE CRITERIA AND TEST STANDARDS
SYSTEM RELIABILITY
ENVIRONMENTAL COORDINATION
TESTS AND APPLICATIONS
FIELD TESTS OF USER-ORIENTED SYSTEMS
INITIAL SYSTEM EVALUATION EXPERIMENTS
ENGINEERING FIELD TESTS
MARKET DEVELOPMENT
MARKET ANALYSIS
CONSUMER INFO
UTILITY INTERACTIONS
MARKET STIMULATION
IMPACTS
INFRASTRUCTURE DEVELOPMENT
CAPACITY GROWTH DYNAMICS
PURCHASE PROGRAMS
PLANNING, ASSESSMENT & INTEGRATION
STRATEGY & PLANNING COORDINATION
PROGRAM INTEGRATION
SUBPROGRAM INTEGRATION
PROGRESS ASSESSMENT
MANAGEMENT SUPPORT

Historically the DOE Photovoltaics Program has been highly goal oriented, in two senses of the word. First, each program element has had the goal of bringing photovoltaics technologies to a well-defined point in the research and development process. The goal of the Advanced Research and Development element, for example, has been to bring promising collector concepts to the technical feasibility stage; the goal of Technology Development has been to establish technology readiness for flat-plate and concentrating collectors and for other PV components and subsystems. The Systems Engineering & Standards and Tests & Applications elements have carried out definition, development, engineering, testing and evaluation activities aimed at demonstrating system feasibility and system readiness. Finally the Market Development element has developed plans and carried out market tests and demonstrations to establish commercial readiness. The meaning of these terms and their interrelationship is provided in Table 3-1 below:

TABLE 3-1.—RD&D PROCESS FOR PHOTOVOLTAIC COMPONENTS AND SYSTEMS—GENERIC MILESTONES IN THE PHOTOVOLTAIC RD&D PROCESS

Milestone	Definitions/requirement
Technical Feasibility (TF) of Components is reached for a particular technology when:	(a) Stable and reproducible performance characteristics have been achieved (b) A laboratory-sale process has been defined that yields products with consistent characteristics (c) Analysis indicates that mass production is technically feasible and likely to yield a technically and economically viable product after suitable technology development.
Technology Readiness (TR) of Components is achieved:	(a) With a successful subscale demonstration of the individual steps in a production process that would yield economically competitive and reliable products if produced in sufficient quantity, and (b) When prototypes are available for intensive performance and reliability analysis.
System Feasibility (SF) is achieved in a given application when:	A photovoltaic system concept is first carried through design, installation, and operation in an actual user's environment.
System Readiness (SR) is accomplished when:	(a) Fully integrated systems, using available technology-ready components or prototypes thereof, are designed, built and successfully operated in an actual user's environment. (b) It is shown that the system price goal and performance goals are likely to be met with high-volume sales.
Commercial Readiness (CR) of Components & Systems in a given application class is accomplished when:	Products or systems in a given application class are offered for sale at a given competitive price.

A second aspect of the goal-oriented nature of the program has been the detailed commercial readiness price goals of systems and collectors used to drive the program. These goals are summarized below:

TABLE 3-2.—COMMERCIAL SYSTEMS GOALS

[Amounts in dollars]

Calendar year of achievement	Applications	Installed system price (1980)
1982	Remote, international	6.00–13.00/Wp
1986	Residential	1.60–2.20/Wp
1986	Intermediate load center	1.60–2.60/Wp

TABLE 3-2.—COMMERCIAL SYSTEMS GOALS—Continued

[Amounts in dollars]

Calendar year of achievement	Applications	Installed system price (1980)
1990	Central station	1.10-1.80/Wp

TABLE 3-3.—COMMERCIAL READINESS GOALS—COLLECTORS

Fiscal year of achievement	Collector price (1980)
1982	2.80/Wp
1986	0.70/Wp
1990	0.15-0.40/Wp

These goals were constructed to be consistent with the objectives of the Solar Photovoltaic Energy Research, Development and Demonstration Act (Public Law 95-590), which was passed by Congress at the Initiative of the Science Committee in 1978. The objectives of that Act were:

1. To double the production of solar photovoltaic energy systems each year . . . so as to reach a total annual U.S. production of solar photovoltaic energy systems of approximately two million peak kilowatts, and a total cumulative production of four million peak kilowatts by fiscal year 1988.
2. To reduce the average cost of installed solar photovoltaic energy systems to $1 per peak watt by fiscal year 1988, and
3. To stimulate the purchase by private buyers of at least 90 per centum of all solar photovoltaic energy systems produced in the U.S. during fiscal year 1988.

To achieve those objectives Public Law 95-590 estimated that an "aggressive research, development and demonstration program" involving "the expenditure of $12,500,000,000 by the Federal Government" over the 10 year period 1979-88 would be required. The PV program later determined that $1.5 billion would not be sufficient to ensure the achievement of objective (1).

RECENT BUDGET CHANGES

In its fiscal year 1982 budget request the Reagan Administration proposed to cut the PV program by 60 percent, from $160 million to $62.9 million, eliminating all funding for Systems Engineering and Standards, Tests and Applications, and Market Development. Technology Development was reduced to $11.9 million to "complete crucial projects in the Low-Cost Solar Array Program managed by JPL and in the Balance of Systems work at the Sandia Laboratories and MIT Lincoln Laboratory." All price and technology goals were dropped or left to industry to achieve. Only Advanced R&D was left untouched, at $44 million.

Congress appropriated $74 million for PV in fiscal year 1982, but redirected a substantial amount of the activity toward Technology Development, Systems Engineering and Standards, and Test and Applications as follows:

Fiscal year 1982 appropriation

	Millions
Advanced R&D	$20.1
Technology development	23.2
Systems engineering and standards	12.9
Tests and Applications	17.8
Total	74.0

For fiscal year 1983 the Administration requested $27 million, all for Advanced Research and Development. Congress added $31 million to that request and redirected funds toward nearer term development and testing, as shown below:

Fiscal year 1983 appropriation

	Millions
Advanced research and development	$23.2
Technology development	15.5
Systems engineering and standards	7.5
Tests and Applications	8.8
Headquarters reserve	3.0
Total	58.0

RECOMMENDATIONS FOR A MULTI-YEAR PHOTOVOLTAICS PROGRAM

Staff recommends the restoration of a balanced photovoltaics RD&D program at close to $65 million/year for the next 4 to 5 years. Advanced Research and Development and Technology Development should each receive about 45 percent of the budget; Tests and Applications and Systems Engineering and Standards should split the remaining 10 percent. Market Development activities will be left to the private sector.

Information provided to the Energy Development and Applications Subcommittee in response to questions raised at its July 28 hearing indicates that $65 million is the minimum needed to enable the photovoltaics program to meet reasonable price goals for technical feasibility within this decade. At that level laboratory technical feasibility for 40 cents/Wp collectors could be achieved by fiscal year 1987; and component technical feasibility could be achieved for the same collectors by 1990. These goals represent significant slippage from the ambitious milestones of the fiscal year 1980 PV Multi-Year Program Plan, and leave the achievement of "technology readiness" and "system readiness" completely in the hands of the private sector. However, they are recommended to provide a direction and focus to the program that is essential to its continued success.

Evaluations of the DOE photovoltaics program have consistently stressed the high quality of its managerial effort. The ERAB Solar Energy R&D Report, for example, found that, "The DOE photovoltaic program has been well managed, as demonstrated by progress in recent years." A report on "Industry's Perspective on Federal Photovoltaic Programs" by Strategies Unlimited for the Solar Energy Industries Association (July 1981) praised JPL and Sandia for "particularly competent management and sensitivity to the needs of industry." Since price goals have been an integral part of this successful management effort, it is recommended that some modified form of those goals be continued. There have been industry criticisms of the former "commercial readiness" price goals. According to the industry survey by Strategies Unlimited cited above:

> Price goals for photovoltaic systems have been too dominant in shaping federal photovoltaic programs. These goals have little economic significance and have been counterproductive by encouraging buyers to wait for future lower prices.

By dropping system readiness goals in favor of laboratory and component technical feasibility targets, the PV program can retain a valuable management tool while responding to the legtimate concerns of industry.

The photovoltaic program at the $65 million/year level would consist of the following activities:

1. Advanced R&D on photovoltaic cell materials and devices, including thin-film amorphous and crystalline materials, polycrystalline silicon physics advanced concentrator cell concepts, cell optimization, and fundamental process research on junction formation and metalization.
2. Technology Development:
    (a) Flat plate collector research and development, including module engineering, process research, cell encapsulation materials, insulation materials for high voltage modules and reliability/durability testing and analysis.
    (b) Concentrator collector research and development, including module engineering, process research, Fresnel lens development and reliability/durability testing and analysis.
    (c) Silicon material and silicon ribbon technology development.
3. Systems Engineering and Standards including technical support to industry standard groups, assessment of current system design and performance requirements to provide basis for future program direction, and balance of systems research and development.[1]
4. Tests and Applications including operation of Residential Experiment Stations and existing experimental photovoltaic residences, operation of existing medium size systems, including PRDA's, operation of existing Data Reduction Center and continued programmatic support of grant projects.

The case for technology development

A number of recent assessments for the DOE Photovoltaics Program have recommended continuation of a strong Technology Development subprogram, managed by JPL and Sandia. The industry report prepared by Strategies Unlimited for SEIA contains the following recommendations for shares of the PV budget apportioned by subprogram:

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[1] BOS R&D activity is somewhat controversial. The ERAB panel "recognizes the importance of BOS cost reductions," but believes that "BOS cost reductions are . . . engineering development areas and industry will take the necessary engineering steps to reduce BOS costs." The PV Advisory Committee (SPEAC), on the other hand, found that "a reasonable effort continues to be required to assure proper oversight and coordination of the so-called balance of system components . . . Continued federal participation is necessary to ensure progress in this area."

[In percent]

	Historical		Recommended 1982
	1980	1981	
Advanced research and development	30	31	27
Technology development	39	38	57
Systems engineering and standards	10	9	7
Tests and applications	15	9	9
Market development	6	13	0

The report explicitly recommended that:

> * * * technology development activities merit expansion within the DOE program. These activities frequently entail high risk for industry, yet might potentially yield large rewards for the technology.

The ERAB Solar Energy R&D Report cited the following activities, which are contained in the technology development subprogram, as deserving further support:

Development of processing techniques.
Development of advdanced processing equipment.
Cost reduction techniques for single crystal silicon materials.
Concentrator System R&D.
Advanced silicon sheet (ribbon technique) R&D.
Research on flat plater module durability.

Roger Little of Spire Corporation, in testimony to the EDA Subcommittee on July 28, 1982, provided the following assessment of the need for government support of photovoltaics technology development:

> Reduction in the R&D efforts associated with the Technology Development area will severely hurt today's industry and make it much less competitive on an international front. . . . It is this area of problem solving and small companies which is most in jeopardy due to Federal Government budget cutbacks. It is this area of PV industry activity that requires the most help, especially for competing in near-term markets.

In the past few years Europe and Japan have made considerable progress in photovoltaics technology development. According to testimony by Dr. Robert Ferber and James Corr at an EDA Subcommittee hearing Jume 3, 1982, the Europeans and Japanese remain behind the U.S. in PV technology because of the lead established by the U.S. program in 1975-80. However, both witnesses perceived a strong threat to U.S. dominance of world photovoltaics markets if the U.S. photovoltaics technology development program is eliminated while other countries are increasing their efforts in this area.

The need to ensure that the threat of foreign superiority in PV technology does not become a reality, and that U.S. industry retains its current leadership in world PV markets, is another justification for continuing an aggressive technology development subprogram.

The case for crystalline silicon

Many analysts believe that only thin films using advanced materials or amorphous silicon can achieve the cost reductions necessary for widespread photovoltaics market penetration. However, recent testimony presented to the EDA Subcommittee indicates that crystalline silicon technology produced by ribbon processes stands an excellent chance of meeting or exceeding program cost goals. According to Dr. Marshall Alper of the Jet Propulsion Laboratory:

> The Solar Energy Research Institute and JPL recently (Feb. 1982) completed a joint, detailed assessment of 19 advanced silicon flat-plate technologies. In the opinion of JPL and SERI researchers, 11 of these approaches had greater than a 75 percent probability of meeting a $1.00/peak watt target, and six had greater than 50 percent probability of meeting the 70 cent/per peak watt goal.

A number of industry and government representatives have argued that further government support for crystalline silicon technology development is unwarranted because the private sector can carry out that activity on its own. JPL has found, on the other hand, that:

> The funding cutbacks in JPL sponsored silicon R&D have led to: (1) a significant decrease of corporate silicon R&D funding at most (but not all) contractors, (2) a reduction in risk taken by the silicon photovoltaic industry and (3) an increased inhibition to the flow of R&D information as complete, privately funded development increases.

To determine the industry view on the need for further federal R&D on crystalline silicon the Energy Development and Applications Subcommittee conducted a survey of photovoltaics manufacturers and research organizations. Questionnaires were sent to a wide range of participants in technology research, development and implementation. A total of 116 organizations were contacted, including (1) flatplate and concentrator collector R&D contractors, (2) manufacturers of PV cells, flat-plate PV panels, concentrator/focusing PV collectors, and PV balance of system components, and (3) energy storage manufacturers and distributors. The organizations include both large and small firms in private industry, universities, and research laboratories. Of those given the opportunity to participate in this survey, 58 responses were returned. Most responses were submitted anonymously.

The results of this survey are summarized below. Substantial support for crystalline silicon PV technology by the PV community was indicated as follows:

1. Future federal support for crystalline silicon PV research and development was favored by 91 percent of the respondants.
2. Crystalline silicon PV was expected to be economically competitive with conventionally generated electricity supplied by U.S. utilities this century by 54 percent of the respondants. Negative responses were only 14 percent.
3. Most of the respondants (76 percent) expressed the belief that it is neither "likely" nor "very likely" that crystalline silicon will be replaced as the dominant PV material this century.
4. Respondents supported silicon material- and cell-related R&D most strongly. Preference was expressed for funding new approaches to high-efficiency silicon solar cells (88 percent of those responding), polysilicon feedstock refinement (79 percent), silicon ribbon growth (84 percent), and high-efficiency

concentrator silicon solar cell design and processing (75 percent).

5. Many areas of module R&D enjoy strong or moderate support (e.g., 70 percent in favor of flat-plate module environmental isolation research.)

Tests and applications

Some existing photovoltaic systems experiments should continue operation in the fiscal year 1984–88 time frame in order to validate research results and provide technical feedback to the Advanced R&D and Technology Development activities. The ERAB Solar Panel recommended that "some system experiments or tests are necessary to resolve important technical issues such as optimum field voltage, design and array field output degradation." These tests can be small in scale and confined to the resolution of technical issues.

The issue of large-scale demonstrations and federal purchases is more contentious. There has been consistent support from industry for a one or more megawatt utility systems experiment. The solar industry panel assembled for the Strategies Unlimited report cited above recomended that:

> The Federal Government should financially support the cost of at least one utility-connected experimental photovoltaic system, with a peak output of greater than two megawatts.

SPEAC also recommended that "a proposed advanced utility research experiment of approximately one megawatt size, which has been planned with cost-sharing from the private sector (the SMUD project), should proceed as rapidly as possible." The SEIA Photovoltaic Division, in testimony before the EDA Subcommittee, cited "the need for a large-scale utility experiment, expanding the SMUD project beyond its initial one megawatt." However, the ERAB Solar Panel recommended the "termination of further DOE funding for the SMUD project."

Clearly the goals of industry can be achieved with funding of the second increment of SMUD in fiscal year 1983 as called for in the House Energy and Water Appropriations report (House Report No. 97–851). The question remains what more should be done, in the future. The original concept of the SMUD project, as put forth in the industy-utility proposals, was to use a $27 million up-front federal investment as risk capital to leverage a 100 MW, $270 million investment by the private sector. This proposed cost-sharing, with industry assuming more and more, and the Federal Government less and less of the risk was one of the most attractive features of the project. It was thought that the guaranteed 100 MW market would give the PV industry an incentive to build production facilities to meet the cost goals of the project.

However, it now appears that the cost goals of the SMUD project may not be feasible. Furthermore, it may not be possible, in the annual appropriations process, to guarantee the up-front DOE investment of $27 million with sufficient certainty to assure industry of the 100 MW market. Thus, it appears that some modification of the approach envisaged by the SMUD project proponents may be desirable.

The following recommendations are made:

1. SMUD project appropriations should be treated as a construction line item, separate from the photovoltaics program, with non-DOE cost sharing of a specified amount greater than 50 percent required.
2. SMUD should consider the possibility of opening the bidding up to photovotaics concentrator and solar thermal electric systems with the sole condition being achievement of price goals. This would more closely simulate an actual utility market in which cost and performance rather than technology would be the main considerations.

The effect of these changes would be to remove the image of the SMUD project as a DOE demonstration and substitute for it the true objective of the funding, namely to provide up-front federal risk capital in order to leverage a much larger private sector investment.

On the issue of federal purchases, Committee staff agrees with the Strategies Unlimited industry report that:

> The Federal Government should ensure that each federal agency, through its normal procurement processes, utilizes photovoltaic energy systems wherever cost effective. Such procurements should be on a competitive basis subject to the standard rules of commercial procurements by the government.

This guidance should pertain to all solar energy systems. DOE should do a study of whether federal agencies, including itself, are purchasing renewable energy systems where cost effective under current Congressional guidelines, if not, what possible actions could be taken to remedy the situation. Special attention should be paid to determining whether the Defense Department is following the directions for use of renewable energy systems in the fiscal year 1983 Military Construction Authorization Act.

Systems engineering and standards

The need for work in systems engineering and standards was well summarized by the Photovoltaics Advisory Committee (SPEAC):

> Continued federal presence in the area of standards and testing is essential to assure orderly progress in the evaluation of PV components and systems. A vital aspect of this program is the continued evaluation (by the Jet Propulsion Laboratory) of about 2 kilowatts annually of each major new type of photovoltaic module entering commercialization.

In addition, it is necessary to document the significant systems research results to date and disseminate these results to industry. It is also necessary to continue the assessment of design and performance requirements to provide a framework for program direction of the recommended goal-oriented program.

Research and advanced development

The Administration has correctly assessed the need for continued research development on advanced and novel photovoltaic materials and cell concepts, at a level of about $25–$30 million a year. Since this is not an area of dispute, this subprogram will not be discussed in detail. However, staff notes that amorphous silicon, polycrystalline thin films and advanced high efficiency concepts have all displayed considerable progress in the past year and will require additional research support to maintain their momentum.

CHAPTER IV.—SOLAR THERMAL ENERGY SYSTEMS

PROGRAM HISTORY

Solar Thermal Energy Systems (STES) convert sunlight to heat, which is then used to produce electricity or mechanical power, or to drive high temperature industrial processes. STES technologies include central receivers, parabolic troughs, parabolic dishes, hemispherical bowls and solar ponds (see technology descriptions, below). The STES program has historically had three missions:

To work with industry to develop and demonstrate technologies for producing electricity and industrial process heat from sunlight.

To carry out applied research and exploratory development on components, processes and materials to reduce the cost and increase the performance of solar thermal energy systems.

To examine the feasibility of using solar thermal energy systems to produce fuels and chemicals.

The STES program has traditionally been the second largest in the overall DOE solar effort. By far the lion's share of the STES budget has been devoted to development and demonstration of the five solar thermal technologies, as the attached budget history shows.

TABLE 4-1.—STES BUDGET BY PROGRAM ACTIVITY: FISCAL YEAR 1978–81

[In millions of dollars]

	1978	1979	1980	1981
Applied research	10.550	5.350	6.105	9.600
Exploratory development	14.950	8.094	24.405	8.250
Technology development	21.107	45.468	52.800	59.550
Engineering development and demonstration	57.493	52.288	58.400	61.750
(Construction of demos)	(41.000)	(28.000)	(37.095)	(31.850)
Planning studies and analyses	0	0	1.325	2.600
Total	104.100	117.200	143.200	141.750
Operating expenses only	63.100	89.200	106.105	109.900

A description of the principal STES technologies and program activities follows:

Central receiver technology development and demonstration

A central receiver system employs a field of sun-tracking mirrors (called heliostats) to focus sunlight on a receiver at the top of a tower. In the receiver a circulating fluid such as water, molten salt, liquid sodium or air absorbs the solar energy and transmits it at high temperature (up to 1500° F) to a storage or energy conversion technology at the base of the tower. There it is either stored at high temperature for future use, converted to electricity or shaft power, or used directly (in the case of water) as process steam.

The DOE central receiver program has worked with four industrial teams (Boeing, McDonnell-Douglass, Martin Marietta and Arco Solar) to develop second generation heliostats which appear capable of meeting the program goal of $100/m2 in quantity (10,000-25,000 units/year) production. It has also tested a variety of receivers, receiver components and storage possibilities.

Its most significant program achievement has been the construction and operation of a 10MWe pilot plant at Barstow, California, at a total cost of $141 million, including $20 million private sector cost sharing. The plant is scheduled to be operated for five years to provide utilities and the supplier industry with real-world data about the performance of central receiver systems and components. The program had originally hoped to follow Solar I with a large system test in which a central receiver would be used to "repower" an existing fossil-fueled plant.

Utility interest in this technology is high: Southern California Edison is evaluating four proposals from industry teams in response to a Program Opportunity Notice to design, construct and sell power from a central receiver in the 100MWe range. Seven utilities participated in the conceptual designs funded by DOE for solar thermal "repowering" of existing fossil fired plants. Three have proceeded to the preliminary design phase with DOE assistance. The economics, using third party financing and ownership in the near term and straight utility financing in the long term, appear marginally favorable.

Parabolic trough development and demonstration

A parabolic trough system uses a long, narrow mirror curved in the shape of a parabola about its principal axis to focus sunlight on a tube through which oil, water or some other fluid circulates and transports the solar energy to a boiler, heat exchanger or storage tank. Because parabolic trough systems both focus and track in one dimension, they produce temperatures in the moderate range (200-600° F) which are best suited to running absoption chillers and industrial processes. Because they are modular, relatively inexpensive and relatively simple technologically, DOE has been able to fund close to a dozen parabolic trough systems experiments and demonstrations. Some of the better designs have performed quite well; others have been dismal failures.

In addition, DOE has worked closely with industry to improve the performance of components, to measure the efficiency of systems and to develop techniques for mass production. As a result of this, effort systems that are more than 60% efficient in turning sunlight into heat, and can be installed for less than $300/m^2, are being marketed by several companies today. Most analysts believe that the parabolic trough technology has reached the commercialization phase and that further technology development can be left to industry. Staff agrees with this assessment.

Parabolic dish research, development and demonstration

A parabolic dish system uses a mirror in the shape of a paraboloid of revolution to concentrate sunlight on a receiver or receiver or receiver-engine combination to produce high-temperature heat of electricity. The most advanced concept places a Stirling or Brayton cycle engine at the point focus to generate electricity directly in about the 20 kw size range. One prototype of this configuration, tested recently at the Prabolic Dish Test Facility at Edwards Air Force Base, produced electricity at 26 percent efficiency from sunlight, a world record, using a Stirling engine. An alternative system would use a fluid to transport the heat from a field of dishes to a central boiler. A large DOE demonstration project in Shenandoah, Georgia, is currently testing this concept for the production of process heat, absorption chilling and electricity for a knitwear factory.

The parabolic dish subprogram began several years after the central receiver and parabolic trough efforts, and, consequently, the technology is still largely in the component development phase. An Organic Rankine cycle module, consisting of concentrator, receiver, engine and controls will be tested at Edwards AFB this summer and will be used in a small community experiment in Osage, Kansas, next year. A contract for developing a complete Stirling cycle module was signed last year. Brayton cycle testing and module development lag somewhat behind.

Hemispherical bowl research and development

A fourth concentrator concept developed at Texas Tech University, uses a large (200 ft. diameter) stationary hemispherical bowl to concentrate sunlight on a movable receiver. The system has been tested in prototype at the 65-foot size, but a planned 10 bowl, 5 MW demonstration project at Crosbyton, Texas, has been cancelled. The technology is highly controversial: proponents point to low system costs (compared to Solar One and Shenandoah) and successful performance in prototype as arguments in its favor; opponents cite inherently low collection efficiencies, potentially large heat losses and the lack of broad-based industry support as arguments against the technology. Independent analyses of the ultimate cost and performance potential of the system have ranged from moderately positive (Pacific Northwest Laboratories) to relatively negative (Jet Propulsion Laboratory, Solar Energy Research Institute).

Solar ponds research and development

Salt gradients in naturally occurring or man-made bodies of water reduce natural convection currents, and thereby reduce heat losses. As a result, the bottom layer of a well-designed solar pond can reach temperatures close to the boiling point of water. Heat can be extracted from the pond and used for space conditioning, industrial processes, desalinization, water purification and electricty generation.

The active solar heating and cooling program at DOE has for some time maintained a modest solar pond program at Los Alamos and SERI, emphasizing research and testing to better understand the characteristics of ponds, and the techniques for maintaining the gradient, reducing wave formation and minimizing convective loses. Independently the Solar Thermal Energy Systems program has examined the feasibility of using solar ponds at the Salton Sea in Imperial Valley in California to generate commercial electric power. Concept and feasibility studies are being completed, and the next phase would involve the design, construction and testing of a 5MWe generating plant to be cost shared by Ormat Turbines, Southern California Edison and the California Energy Commission.

Materials, components and sunfuels advanced research and development

This is the technology base part of the STES program, which carries out the generic long-term, high-risk advanced research and exploratory development needed to support the technology subprograms. It also explores the possibility of using high temperature STES systems to produce fuels and chemicals. The Materials Research and Development subprogram examines failure mechanisms and possible substitute materials for mirrors, coatings and heat transfer fluids, with the goal of developing new high-performance materials that can be transferred to industry. The applied research subprogram develops and tests advanced components such as receivers, heat exchangers and thermochemical transport systems with the goal of improving the performance/cost ratio of STE systems. A supporting research program provides support to the university and user communities for long-term basic and applied research at solar thermal test facilities at Sandia Albuquerque and Georgia Tech. The Sunfuels subprogram conducts studies and subscale experiments to determine the feasibility of using existing chemical and thermal processes to convert non-renewable feedstocks and biomass into fuels and chemicals using heat from STES systems.

Although essentially a long-term research program, the advanced R&D element has suffered sharp funding reductions due to pressures from nearer-term technologies under the Carter Administration and overall solar budget cuts under President Reagan.

RECENT BUDGET HISTORY

Fiscal year 1982

The Carter Administration budget request for Solar Thermal Energy Systems for fiscal year 1982 would have been $85.3 million, with no funds set aside for a repowering demonstration. President Reagan reduced that request by nearly 50 percent to $44 million. The bulk of the reduction came from ongoing technology development projects and systems experiments. Congress, at the initiative of the House Committee on Science and Technology, restored nearly $15 million to the STES budget (including $4 million from a "solar reserve account") and redirected $10 million from research and advanced development to the technology development programs.

Fiscal year 1983

For fiscal year 1983 the administration proposed an STES budget of $18 million, which included funds to operate Solar One and install computer hardware ($9.5 million), but eliminated all the technology development programs, operation of demonstrations and test facilities and support to industry or the research community.

Congress, on the other hand, recommended a $47.5 million budget for Solar Thermal Energy Systems distributed as follows:

> DOE is to maintain technology and systems development activities related to solar thermal central receivers and parabolic dishes. The program shall include installation of software and continued operation of Solar 1 (Barstow) as request by the Administration (9.5 million); development of advanced receivers, steam generators and storage systems ($7 million); and operation of the central receiver test facility at Sandia ($3 million). For parabolic dishes the activities should include continuation of Brayton module development ($3 million); advanced concentratory development ($2 million); applied research ($2 million); testing of organic Rankine Cycle and Stirling modules and operation of the parabolic dish test facility ($2 million); operation of the Shenandoah large experiment ($1.5 million); and a second Small Community Experiment using Stirling and/or Brayton modules ($3 million). An amount of $2 million is provided for the Salton Sea Solar Pond project and $3 million for a single cost-shared repowering preliminary design.

RECOMMENDATIONS FOR A MULTI-YEAR STES BUDGET

The following recommendations for a multi-year Solar Thermal Energy Systems program are organized around two primary activities:

1. The orderly phaseout of existing technology development programs based upon the state of the technology and the ability of the supplier and user industries to carry out needed development, demonstration and testing activities.
2. Restoration of a healthy Research and Advanced Development program at close to fiscal year 1981 levels including work on materials, components, sunfuels, and support to the university and users communities.

These two activities can be covered by a budget that starts (in 1984) at $50 million and gradually decreases to $40 million by 1987. The recommendations are based on testimony given at Energy Development and Applications Subcommittee hearings March 16, May 28 and July 28, 1982 by Byron Washom of Advanco Corporation, Robert Cassanova of Georgia institute of Technology, Harold Seielstadt of Pacific Gas and Electric Company, Daniel Shine of Sanders Company, Alvin Hildebrandt of the University of Houston, and Merwin L. Brown of the Arizona Public Service Company; as well as meetings with industry and national laboratory officials, and a number of multi-year planning documents that have been prepared by individuals and groups associated with the STEA program.

Central receivers

The central receiver technology has reached the engineering development/commercial demonstration phase in which private industry must assume the primary burden for developing the technology. However, there are a number of areas in which federal support is needed to enable industry to complete the transition. Most important of these is completion of the test program for Solar One as originally provided for in the contract between the Department of Energy and Southern California Edison. This need was well expressed by the ERAB Solar R&D Panel:

> The paramount requirement of the federal solar thermal central receiver program over the coming years is to ensure that the Solar One experiment is carried through to a logical and thoroughly understood conclusion. Success in this activity will require completion of the plant's automatic control system, extensive operation coupled with thorough evaluation of the plant's performance and operating requirements, and dissemination of test data and operating experience to all interested parties.

A second crucial activity is support for the development and testing of advanced components such as receivers, steam generators and storage. According to the Solar Thermal Energy Association, one of the "barriers impeding the introduction of the central receiver technology into the private sector" is "performance uncertainties on certain key components:"

> Both the user industry and the venture capitalists [according to STEA] have expressed concern about the fact that one of these key components, the receiver, does not have a counterpart in current industrial practice. In order to remove this barrier and to reduce the perceived risk on this component to the point at which the private sector can pick it up and develop it for commercialization, the industry recommends a base technology program . . . [with] . . . a fiscal year 1983 budget of $3.3 milion . . . applied to both the sodium- and salt-cooled concepts . . . and . . . out year budget recommendations of $4.1 million of fiscal year 1984 and $3 million for fiscal year 1985.

Salt and sodium steam generators have also, according to STEA, not been developed in the temperature range and operating mode needed for solar applications. Budgets of $2.8 million in fiscal year 1983, $4 million in fiscal year 1984 and $1.1 million in fiscal year 1985 are needed. Finally, the "design, fabrication test and analysis" of a "storage concept that is low in cost and economically viable beyond 12 to 18 hours" is also needed to help industry develop the central receiver technology. Budget of $1.6 million, $0.8 million and $0.4 million are recommended in fiscal year 1983, fiscal year 1984 and fiscal year 1985 respectively.

A third area of needed federal assistance is in continued operation of existing test facilities. The successful transfer of central receiver technology to the private sector requires that the Central Receiver Test Facility at Sandia Albuquerque continue to operate at least through the completion of the component development program and that the Advanced Components Test Facility at Georgia Tech be operated in a cost-sharing mode indefinitely or until a private sector party can be found to assume the federal role.

The last federal support area related to central receiver technology concerns the repowering demonstration. The need for and desirability of a federally sponsored solar repowering demonstration was firmly established in testimony before the EDA Subcommittee in March, 1980, and March, 1981. Within current budget and philosophical limitations, it is no longer possible to contemplate a fully federally sponsored repowering demonstration. Moreover, with the recent response of industry teams to the Southern California Edison central receiver program opportunity notice, it is possible that private industry, with the help of federal and state tax credits and accelerated depreciation allowances, may build the first commercial size central receiver power plant on its own, operating as a stand alone unit selling power to the grid.

But it is also possible that the SCE contracts may not materialize and that without a repowering demonstration, the real world experience needed to verify cost and performance estimates for large-scale molten salt or liquid sodium systems will not be available. The solar industry has proposed that DOE fund detailed design on one electricity and one industrial process heat repowering application to narrow cost uncertainties to the plus or minus ten percent range. Since this involves a federal investment of about $15 million, instead of the $250 million or more originally envisaged for repowering demonstrations, it appears to be a prudent step for the Federal Government to take in order to insure its $300 million investment in this technology. Further support for repowering applications beyond the detailed design stage may be required if the third-party financed arrangements being discussed with Southern California Edison are not successful.

All of the recommended R&D activities for solar central receivers could terminate as early as fiscal year 1986.

Parabolic trough

Parabolic trough systems are being commercialized by industry. The only federal role is to conduct generic research on materials and components—such as selective coatings, reflective surfaces, adhesives, advanced receivers—as described under "Research and Advanced Development" below. Continued operation of the Modular Industrial Solar Retrofit (MISR) test systems and other demonstration projects that have recently been completed to collect data, where appropriate, is also warranted.

Parabolic dish

The ERAB Solar R&D Panel correctly recommended that:

> DOE should provide a redirection of emphasis to the parabolic dish program because of its potentially higher efficiencies and lower costs. Future component research should concentrate on areas that will either significantly improve known efficiencies, extend the useful life, or reduce the capital and operating costs of the module. Small multi-module experiments should be programmed on a cost-sharing basis.

The parabolic dish is the only one of the three mainstream technology subprograms in the STES program that remains in the technology development phase. Studies by SERI and JPL in 1980 and 1981 indicated that Brayton or Stirling cycle dish systems were likely to be the most economical producers of electricity among Solar Thermal Energy Systems in the 1–10 MWe range. Consistent with the general principle set forth in chapter one of this report that federal support should continue for technology development of promising solar energy systems, the existing dish program should be completed. That means developing and testing two generations of complete Stirling and Brayton cycle modules; carrying out research and development on advanced concentrators, receivers, control systems and storge concepts and cost-sharing in multi-unit tests in a user environment for both Stirling and Brayton systems.

Multi-unit experiments of sufficient size to obtain meaningful data about the likely performance of a large parabolic dish field can be built and operated at a total cost to the Federal Government of less than $5 million apiece with cost-sharing. It is also desirable to fund the development of second generation Brayton and Stirling parabolic dish module, in the 1985 time frame to take advantage of new developments in high-temperature (e.g. ceramic) engines or receivers or advanced concentrators.

These recommendations provide that all development and demonstration activities for parabolic dishes—including multi-module experiments and second-generation systems development for both the Brayton and Stirling cycles—be completed with funding through fiscal year 1987.

Hemispherical bowl

Despite vigorous promotion by its developers this technology has not received independent support from industry or the analytical community. Studies by SERI in 1980 and JPL in 1981 indicated that electricity generated by mature hemispherical bowl systems would cost 40-50 percent more than electricity generated by comparable parabolic dish Stirling or Brayton cycle systems. The Solar Thermal Program Review Panel, in 1981, stated its belief that:

> The Crosbyton project should be terminated unless it can be demonstrated in fiscal year 1982 that the performance and costs of energy are comparable to those expected from central receiver and parabolic dish technology.
>
> The Department of Energy's "Technical Evaluation and Cost Potential of the 5 MWe Crosbyton Project" in 1982 found that:
>
> In spite of optimistic assumptions regarding the cost of the bowl concentrator, none of the studies have indicated that the cost savings related to the fixed structure of the bowl concept would overcome intrinsic annual performance disadvantages of a non-tracking collector.

The ERAB Solar R&D Panel recommended against further support for the technology. "The hemispherical bowl program should be discontinued because of low average efficiency and costly thermal energy transport."

This lack of broad support for bowl technology makes it difficult to recommend further funding. DOE should fund a complete, independent assessment of the potential and technical problems facing bowl technology, with the goal of determining whether further support in the form of modest component development contracts or small systems tests is warranted in the fiscal year 1985-86 time frame.

Solar pond

The DOE Solar Pond program is in a remarkable degree of chaos for a small research effort. Work has been carried out at four national laboratories (SERI, JPL, PNL and LANL) under the sponsorship of two separate programs (Solar Heating and Cooling and

Solar Thermal Energy) and directed at four different potential end uses (space heating, electric power, industrial process heat and desalinization). JPL was, at one time, interested in co-sponsoring, along with Southern California Edison and the California Energy Commission, a 5 MWe proof-of-concept experimental pond at Salton Sea, as a step toward a privately-owned 600 MWe power producing facility. PNL, on the other hand, has proposed to cost share in the instrumentation, outfitting and operation of an intermediate-sized (10–15 acres) experimental pond to be built by industry at Great Salt Lake. A study of the "Regional Applicability and Potential of Self-Gradient Solar Ponds in the United States" by JPL finds a large potential market (9 quads total) spread over four applications areas—buildings, process heat, electric power and desalinization—and located largely in the Southwest and Gulf Coast regions. But the study does not indicate which applications offer the best near-term market.

The first need for this program, therefore, is to establish a single program office at DOE headquarters and a single multi-year research and development plan that is agreed to by the entire solar pond community. The second is to determine what kind, if any, of large experimental facility is needed to resolve the technical and economic issues that cannot be addressed with existing small pond test facilities. Right now the program appears to be attempting to piggy-back on special opportunities, rather than defining for itself the type of facility it would like to build.

Third, a decision appears needed on which end use the program should address for early systems tests and applications. Using a low temperature heat source like a solar pond to produce high quality electric energy may not be the best first application for the technology. Although the ultimate economics for electricity appear competitive, the 600 MWe size range required to achieve economies of scale appears to have capital requirements (more than a billion dollars) that exceed the levels that a normal utility is likely to invest in an unproven technology. Thus, the program should focus on an early application that has a potential for cost-effectiveness in smaller sizes, such as district heating or industrial process heat.

There appears to be consensus among experts that further research would be useful on topics such as thickness and maintenance of the convecting and nonconvecting zones; pond transmissivity; heat loss to the ground; heat extraction; heat rejection and wind effects. Thus a $2 million a year basic research and development program for solar ponds appears warranted. However, many of the interesting research questions may not be ultimately relevant to the cost and performance of commercial ponds, so it is important that the program carry out a large-scale co-funded system experiment connected with a promising near-term application for which there is user interest.

Restoration of a healthy research and advanced development program

Review of the considerable testimony and literature in the field supports a long-term Research and Advanced Development (RAD) program at the historic budget level of $20 million a year. This program would include research and exploratory development on materials, components, processes for making fuels and chemicals and support to the university and industrial user communities. The RAD program was cut by Congress in fiscal year 1982 in order to make funds available for the more urgently needed task of completing the technology development programs in an orderly fashion. As these programs reach completion in fiscal years 1985–87, the RAD program can be restored to its former levels without placing undue strain on the overall solar budget. The ERAB Solar R&D Panel supports this contention:

> DOE programs in basic and applied research related to solar thermal R&D need a much sharper focus with increased funding for advanced technology base development to support the next generation of solar thermal systems: advanced materials with good optical, thermal, and structural properties, advanced low-cost structures and advanced processes should be examined.

The Research and Advanced Development Program should consist of the following elements:

Materials R&D

Optical materials, including polymer laminates, polymer reflectors, mirror degradation research, thin glass sandwich development and others.

Advanced high temperature heat transfer and storage materials, including containment and fluids.

Thermal materials, including ceramics, regratory metals, high temperature optical windows, direct and selective absorbers.

Component R&D

Receivers: quantifying thermal losses for external and cavity receivers; in situ boiling receivers; design studies; high-temperature gas receivers; receivers/reactors for sunfuels application.

Innovative collectors: low-cost concentrators, secondary concentrators, innovative heliostats.

Thermal subsystems: including direct contact heat exchangers; high temperature storage; chemical storage; chemical transport.

Fuels and chemicals R&D

Hydrogen production from water. Renewable and non-renewable feedstocks. Chemicals production. Photochemical reactions. High temperature kinetics. Photon assisted thermochemical reactions.

(This activity awaits a detailed multi-year program plan which is currently in preparation at DOE.)

Advanced development

Innovative research experiments at the solar thermal test facilities. University programs.

Role of the national laboratories

Committee staff recommends that Sandia and JPL continue to play their lead center roles as long as the technology development programs remain in place (i.e., through 1986). SERI should take the lead in Research and Advanced Development.

TABLE 4-2.—RECOMMENDED BUDGET FOR STES, FISCAL YEARS 1984-87

[In millions of dollars]

1983	1984	1985	1986	1987
Central receivers:				
Barstow completion and operation	4.0	3.2	3.0	
Repowering	8.0	4.0		
CRTF operation	2.0	1.0	1.0	
Component development and testing	6.8	5.5	5.0	
(Receiver)	(3.0)	(2.0)		
(Steam Generator)	(3.0)	(2.1)		
(Storage)	(0.8)	(0.4)		
Subtotal	20.8	13.7	9.0	
Parabolic trough				
Parabolic dish:				
Small community S.E.	3.0	3.0	3.0	3.0
Baryton module development	4.0	3.5	2.5	0.5
Concentrator development	2.5	3.5	2.5	2.0
Stirling (tests and 2d generation)	3.8	2.8	1.1	1.0
PDTS operation	1.0	1.0	1.0	1.0
Applied research and receiver development	2.0	1.0	2.0	2.0
Subtotal	16.3	14.8	12.1	9.5
Solar pond RD&D	2.0	2.0	2.0	2.0
Research and advanced development:				
Materials R&D	4.0	4.0	5.0	7.0
Component R&D	7.2	4.6	5.1	6.4
Sunfuels	2.0	3.7	6.8	8.4
Advanced development	2.0	2.0	2.0	2.0
Subtotal	10.2	15.3	18.9	23.8
Planning and assessment	2.0	2.0	1.0	1.0
Total	51.3	47.8	43.0	38.3

CHAPTER V.—SOLAR BUILDINGS ENERGY RESEARCH

ACTIVE SYSTEMS

Active solar energy systems for space and water heating have been on the market in substantial volume in the U.S. for over seven years. More than 500,000 systems are in use, supplied by more than 300 solar equipment manufacturers and installed by more than 1,800 installation firms in the field. Sales volume for active solar equipment totaled about $500 million in 1982.

Despite the impressive amount of activity taking place in the private sector, there are several reasons why further federally-sponsored research and development is needed to enable active systems to realize their full potential cost-effective contribution to the nation's energy needs. First, a number of promising active solar technologies, such as solar cooling systems, are not yet developed to the point of commercial viability. Second, the development of innovative materials or lower cost, higher performance components could dramatically improve the cost-effectiveness of active solar heating and cooling equipment. Third, the active solar heating and cooling industry is too fragmented and undercapitalized to carry out the needed research and development on its own. In the words of the ERAB Solar R&D Report:

> Of the several thousand small (active solar) manufacturers, most are under-capitalized and none has the financial or the technical ability to do research of any significance. Most imitate the products which are already on the market. Many of the large manufacturers which entered the solar field in the 1970's have since withdrawn. . . .
>
> At the present time, there is no active solar cooling industry in the United States, and a homeowner who wishes to install an active solar cooling system must look to Japan to find one. . . . The only manufacturer which offers completely integrated solar heating and cooling systems is the American Yazaki Corporation, a Tokyo-based manufacturer with an office in Dallas.

Program history

The funding profile for the DOE (and formerly ERDA) Active Solar Heating and Cooling program from 1975–82 is shown in Figure 5-1 below. From 1976–80 the budget was dominated by the Solar Heating and Cooling demonstration program mandated by Public Law 93-409. Under that program, more than 700,000 square feet of solar collectors were purchased by DOE and HUD, representing more than 270 commercial projects and 1250 residential units, and involving more than 70 solar equipment suppliers. According to the DOE Sunset Review:

For many of these suppliers the DOE Demonstration Program was their prime source of sales during their early development. While the program is not solely responsible for the growth of the industry, it has accelerated its development.

Critics of the federal solar heating and cooling demonstration program have pointed out that many of the systems funded by the program were expensive or did not work well. The GAO, in its review of the HUD residential demonstration program in October 1979, found that:

> The program has had only limited success in demonstrating that solar heating is practical. . . . Over one half (of the projects examined by GAO) were either not working or experiencing continual operational problems. . . . These projects have also not clearly demonstrated the economic viability of solar heating systems.

With respect to the DOE commercial buildings demonstration program the GAO was even more critical:

> In general, GAO found that many of the projects are not operating properly and most are not cost effective. Data collection has been relatively slow, and it is doubtful that much of the information collected is reaching the target audience. Also, the Department of Energy does not know what impact its program is having in fostering development of the solar industry.

A $98 million (authorized) federal Solar Buildings Demonstration program was also carried through one cycle (about $35 million) during this time period.

In addition to the demonstration program, the DOE Active Solar program carried out information dissemination activities, in part through the Regional Solar Energy Centers and in part through the National Solar Heating and Cooling Information Center (now called the Conservation and Renewable Energy Information and Referral Service); support to industry to develop codes and standards and overcome institutional barriers; and a modest hardward development program, aimed at reducing the costs and improving the performance of systems and components.

By 1981, the program had come to be comprised of four major elements: materials and components R&D; technology development (chillers, heat pumps and solar ponds); systems tests and evaluation; and industry support (see table 5-1). In fiscal year 1982 the Administration proposed and Congress agreed to the elimination of industry support activities and a sharp decrease in the system test and evaluation subprogram. The Administration proposed to terminate the entire active systems program in fiscal year 1983, moving basic and applied research in materials and components to the Solar Thermal Energy program. However, both House and Senate Energy and Water Appropriations reports contained $6.75 million in funds for active solar heating and cooling.

FIGURE 5-1. OFFICE OF SOLAR HEAT TECHNOLOGIES BUDGET HISTORY

($ in millions)

	1975	1976	1977	1978	1979	1980	1981	1982
Active	12.5	52.7	97.6	91.3	90.4	65.1	41.4	11.5
Passive	0.0	0.0	1.4	7.8	23.9	32.9	30.2	10.6

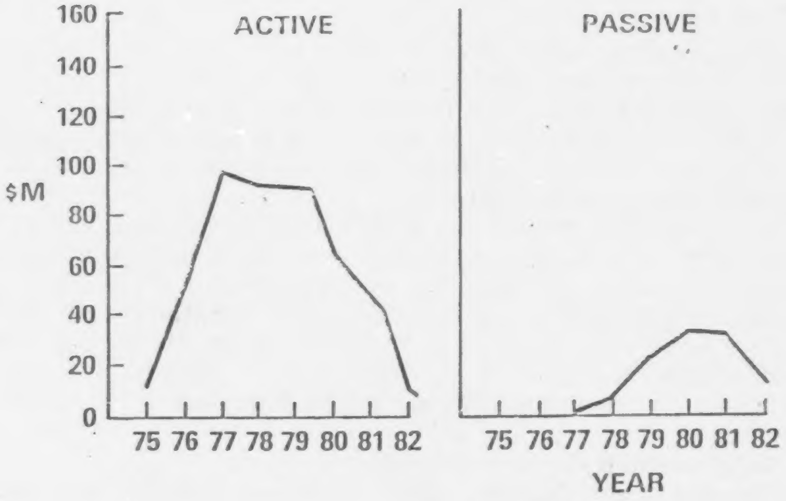

TABLE 5-2.—ACTIVE HEATING AND COOLING PROGRAM FUNDING BY MAJOR ELEMENTS

[By fiscal year, in millions of dollars]

Program elements	Fiscal year 1981	Fiscal year 1982 request	Fiscal year 1982 appropriation
Materials and components: collectors, storage, ponds, materials	2.5	2.1	4.4
Technology: chillers, solar heat pumps, heating/cooling systems	6.2	5.5	2.5
Systems test and evaluation	11.1	3.4	4.1
Industry support	20.4	0	0
Capital equipment	1.2	0.5	0.5
Total	41.4	11.5	11.5

Recommendations

A substantial amount of long term, high risk R&D, which will improve the cost and performance characteristics of active solar systems and not duplicate private sector efforts, remains to be done. This is true for all three remaining program areas: materials and components R&D, technology development, and systems tests and evaluations. This judgment is based on a review of program planning materials provided to DOE by the national laboratories and industry, including a report by Booz Allen and Hamilton, Inc., entitled, "Recommendations to the Department of Energy on the Research Needs and Priorities for an Integrated Solar Thermal Energy Conversion Technology Base" (January 1982), and a report by DHR Incorporated entitled, "Active Solar Energy System Materials Research Priorities" (June 1982). Detailed recommendations follow below:

1. Materials and Components R&D:

(a) *Collector Materials R&D.*—Development of new low cost, light weight, high performance materials, including new polymers (resins, glasses, plastic/metal laminates); new rigid foam materials capable of withstanding high temperatures; higher efficiency coatings and evacuated glazings. Development of new materials to improve the reliability and durability of collectors, such as sealants (silicones and modified elastomers) and coating protection.

(b) *Desiccant Materials.*—Research to establish properties of new desiccatants and to improve existing materials.

(c) *Advanced Collector Research.*—Development of low cost high performance collector concepts, including investigation of the properties of polymeric collectors (flow distribution, heat transfer, reliability). Development of high performance collectors for cooling, including CPCC and vapor generating collectors.

(d) *Storage.*—Research on advanced storage materials for active systems.

2. Technology Development:

(a) *Chillers.*—Historically the DOE Active Solar Cooling program has sponsored the development of three different chiller technologies: absorption cycles, Rankine cycles and desiccant cycles. Although considerable progress has been made, none exist with sufficiently high COP (1.5 or greater) or sufficiently low cost potential to enter the marketplace. It appears that both absorption and desiccant chillers could benefit from further research and development. Therefore, a modest development program involving parallel contracts on these two chiller technologies is recommended. Successfully developed low cost or high performance chillers could find an early market in conventional fuel applications. It is recommended that DOE seek cooperative support from private research organizations for this program area.

3. Systems Tests and Evaluation:

(a) *System Tests.*—Testing of advanced concepts to determine performance and cost baselines. Development of standardized test procedures.

(b) *Systems Analysis.*—Development of system models for advanced concepts in order to identify needed further R&D and to set cost and performance targets.

(c) *Performance Monitoring.*—Continued monitoring and data collection from existing sites in the National Solar Data Network set up as part of the solar heating and cooling demonstration program. Possible expansion of private sector sites for better comparisons.

(d) *Systems Controls.*—Research on controls for advanced systems, such as solar cooling.

All of the recommended research and development could be carried out within a budget of $12 million a year over the next four years. A proposed budget for active solar heating and cooling R&D is presented below.

TABLE 5-3.—PROPOSED BUDGET FOR ACTIVE SOLAR HEATING AND COOLING R&D

[By fiscal year, in millions of dollars]

	1984	1985	1986	1987
Materials and components R&D:				
Collector materials	1.5	1.5	1.5	1.5
Desiccant materials	1.5	1.5	1.0	1.0
Advanced collector R&D	1.0	1.0	1.0	1.0
Storage	0.5	0.5	0.5	0.5
Subtotal	4.5	4.5	4.0	4.0
Technology development—Chillers:				
Absorption	1.0	1.0	1.0	1.0
Desiccant	1.0	1.0	1.0	1.0
Subtotal	2.0	2.0	2.0	2.0
Systems tests and evaluation:				
Systems test (and procedures development)	1.5	1.5	1.5	1.5
Systems analysis	1.5	1.5	1.5	1.5
Performance monitoring	1.0	1.0	1.0	1.0
Subtotal	4.0	4.0	4.0	4.0
Total active solar	10.5	10.5	10.0	10.0

PASSIVE SYSTEMS

Passive solar techniquest involve using building components--windows, walls, roofs and floors—and design strategies to capture sunlight and use it for heating and lighting, or to cool the structure. By the end of 1982 more than 100,000 passive solar buildings had been constructed, and interest is very high in both the architectural and the home building communities. However, most of this activity is focused on the use of simple passive solar techniques for space heating in single-family residences. Passive cooling is poorly developed and not widely used despite considerable potential in hotter and more humid climates. Commercial building passive design, and especially the use of daylighting, is still subject to great uncertainty and requires further development. The ability to model, analyze and predict systems performance remains quite rudimentary. Heat transfer both into and within passive solar buildings is still poorly understood. Finally, new aperture, storage and heat transfer materials could dramatically improve the performance, or lower the cost of passive solar systems.

Some research and development in the above areas is being carried out by the buildings trade associations, such as the NAHB Research Foundation, AIA Research Corporation and ASHRAE. However, as the ERAB Solar R&D Panel noted, "There is as yet no real U.S. passive building industry." Furthermore, as DOE Assistant Secretary for Conservation and Renewable Energy, Joseph Tribble, pointed out in testimony to the EDA Subcommittee, July 22, 1982:

> The building industry is very fragmented and contains many relatively small businesses. It is difficult for these individual businesses to focus on research and development which serves a common interest.

Moreover, passive solar design research does not lead to results which can be easily patented or appropriated for profit by an individual firm. For these reasons a continued federal R&D presence in passive solar energy is warranted.

Program history

As can be seen from figure 5-1 (above) and Table 5-4 (below), the DOE Passive and Hybrid Systems Program started several years after the Active Heating and Cooling Program and reached a peak funding level of $30.9 million in fiscal year 1980. In the first two years the program focused exclusively on residential buildings and primarily on heating applications. In fiscal year 1980 commerical building and cooling elements were added, but the emphasis on heating and residential applications remained.

According to the DOE Sunset Review, the Passive and Hybrid Solar Energy Program had the following historic objectives and accomplishments:

1. To conduct R&D to indentify cost and performance characteristics, develop an understanding of physicial phenomena, and document system, materials and components for passive heating and cooling. Accomplishments: cost/performance goals established; good understanding of single zone heat transfer and operation of three heating systems.

2. Develop analytical methods for rigorous technical and economic assessment of passive solar homes. Accomplishment: reliable computer codes and models developed and validated, plus passive added to existing heating and cooling load models.

3. Develop a range of passive and hybrid components and products which can be easily integrated into conventional practice. Accomplishment: 12 component projects reach stage for private sector commercialization.

4. Develop marketable designs for new and retrofit residential and commercial buildings. Accomplishment: over 300 residential designs available—33 commercial buildings prototypes developed. Prototype designs available to manufacture housing industry, representing 39 percent of new home construction.

5. Field test passive heating and cooling systems in new and retrofit residential and commercial buildings. Accomplishments: over 300 buildings field tested. Data for 4 years of experimental buildings collected and disseminated.

6. Develop and disseminate design tools for architects, builders and designers. Accomplishment: residential design tool for heating mostly done—commercial 50 percent complete.

TABLE 5-4.—PROGRAM ELEMENTS

[By fiscal year, in millions of dollars]

	1978	1979	1980	1981	1982
Residential buildings	7.7	23.9	15.2	16.1	3.813
Commercial buildings	0	0	7.5	8.7	2.526
Materials and components	0	0	1.9	2.5	1.250
Solar cities and towns	0	0	1.7	2.0	0
Agriculture	0	0	.1	0	0
HQ and general program support	0.1	0	0	1.6	1.299
CE	0	0	0	0	0.440
Total	7.8	23.9	26.4	30.9	9.328

The fiscal year 1982 budget request and appropriations for the passive solar program are presented in Table 5-5 below. For fiscal year 1983 the Administration requested no funds for this program. House and Senate Appropriations Committees have both recommended $5 million.

TABLE 5-5.—PASSIVE AND HYBRID SOLAR ENERGY PROGRAM FUNDING BY MAJOR PROGRAM ELEMENTS

[By fiscal year, in millions of dollars]

Program elements	1981	1982 request	1982 appropriation
Materials and components	1.9	1.1	2.0
Buildings systems:			
Residential	17.7	4.6	4.6
Nonresidential	10.1	4.4	3.5
Capital equipment	.5	.2	.5
Total	30.2	10.3	10.6

Recommendations

A workshop on Building Energy Research co-sponsored by DOE, the House Committee on Science and Technology, EPRI, GRI, AIA, NAHB/RF and ASHRAE was held on January 12-14, 1983. Its recommendations describe a potential research agenda for passive solar systems, in coordination with an overall buildings energy research program. Based on that workshop, and on testimony to the EDA Subcommittee and internal planning documents prepared by and for DOE, staff recommends a $15 million/year passive solar budget oriented around six primary activities. These are materials R&D; heat transfer research; performance monitoring and evaluation; modeling and systems analysis; daylighting simulation and analysis; and passive cooling. A more detailed discussion follows:

1. Materials Research and Development:

    (a) *Aperture materials.*—Development of low conductance, low convection glazing materials such as microporus amorphous and crystalline materials or evacuated or heavy gas-filled glazings to reduce heat loss through apertures. Development of optical filter and optical switching glazing materials and alternative means for directional control of energy flows (holography, microgrids and fiber optics) to control the reflection and transmission of characteristics of apertures.

    (b) *Thermal storage materials.*—Development of solid-solid and advanced solid-liquid phase change materials which can be readily incorporated into conventional building components and practice. Development of stable low cost latent heat of storage materials such as boiling or condensing vapors.

    (c) *Heat transfer materials.*—Development of advanced heat transfer materials—such as vapor phase materials and heat pipe roof, wall and floor materials—to enhance and provide optimal control over heat transfer rates. Development of improved heat transfer fluids with low viscosity and high thermal capacity.

2. Basic heat transfer research:

    (a) Sensitivity studies, empirical tests and selective experiments to test and verify convection coefficients and interzone coupling algorithms.

    (b) Studies and experiments to measure convective heat transfer rates between enclosures within buildings.

    (c) Empirical and analytical studies of heat transfer rates in heat pipes and convection/conduction mechanisms in liquid phase change materials.

    (d) Effect of moisture migration of heat transfer in solids.

3. Performance monitoring and evaluation:

    (a) *Building component testing.*—Proof-of-concept testing of advanced materials and components. Laboratory and full-scale prototype tests in instrumented cells and buildings.

    (b) *Advanced systems validation.*—Tests to obtain performance data on advanced prototype systems and to validate analytical tools. Validation of residential, commercial and institutional buildings models. Validation of daylighting and innovative systems models. Comparisons between predictive techniques and actual system responses.

(c) *Thermal performance monitoring.*—Continue to monitor and collect data from existing passive solar field tests and demos.

4. Modeling and Systems Analysis:

(a) Building-level systems analysis of residential and commercial applications.

(b) Analyses of specific passive systems and of the influence of individual passive elements on overall building performance.

5. Daylighting simulation and analysis: Incorporate daylighting into passive solar design. Characterize natural lighting phenomena. Develop calculation techniques. Measure solar illumination in divers regions. Take measurements on scale models in simulated conditions.

6. Passive cooling: Identify methods for passive cooling. Provide engineering rules for cooling load avoidance and passive heat rejection. Develop advanced cooling concepts and materials.

A recommended multi-year budget for these activities is provided below:

TABLE 5-5.—PROPOSED BUDGET FOR PASSIVE SOLAR R&D

[By fiscal year, in millions of dollars]

	1984	1985	1986	1987
Materials R&D:				
Aperture materials	2.5	2.5	2.5	2.5
Storage materials	2.5	2.0	2.0	2.0
Heat transfer materials	1.0	1.0	1.0	0.5
Subtotal	6.0	5.5	5.5	5.0
Heat transfer research	2.0	1.5	1.0	.5
Performance monitoring and evaluation:				
Component testing	1.3	1.3	1.3	1.3
Systems validation	1.7	1.7	1.5	1.0
Performance monitoring	1.0	1.0	1.0	1.0
Subtotal	4.0	4.0	3.8	3.3
Systems analysis and models	1.3	1.3	1.3	1.3
Daylighting	1.0	1.0	1.0	1.0
Passive cooling	1.5	1.5	1.5	1.5
Total Passive Solar	15.8	14.8	14.1	12.6

CHAPTER VI.—BIOMASS AND ALCOHOL FUELS

Biomass has the potential to be the Nation's leading supplier of renewable energy by the year 2000. The Office of Technology Assessment, in its report on "Energy From Biological Processes" (1980), estimated that 6-17 quads of energy could be supplied by wood, wood wastes, plants, plant residues and animal wastes by the end of the century, with the lion's share being provided by wood. The Energy Research Advisory Board Panel on Biomass Energy estimated the potential contribution of the same sources in the same timeframe at about 9 quads gross energy input (Biomass Energy, November 1981). By comparison, the entire energy contribution of all the solar technologies being developed by the Department of Energy—active and passive solar, solar thermal energy, photovoltaics, wind and OTEC—was estimated by the Solar Domestic Policy Review to be 8.6 quads in the year 2000 for its "Maximum Practical Case."

Currently, biomass provides slightly less than 2 quads of energy per year, primarily from direct combustion of wood in the Nation's pulp and paper mills (about 1.4 quads) and in wood stoves for home heating (about 0.5 quads). These two applications alone, however, will not enable biomass to achieve its full cost-effective potential. New technologies must be developed to convert biomass feedstocks to liquid and gaseous fuels, and new techniques for growing and harvesting biomass crops must be developed to provide sure sources of supply near the end user. Some activity is already taking place in these areas: low BTU wood gasifiers and simple alcohol stills are available on the market, and forest managers are developing techniques to increase the yield of firewood from the Nation's forests. However, the longer-term high payoff processes, such as medium-BTU wood gasification, production of alcohol from ligno-cellulosic feedstocks, and growth of new land- and water-based crops for gaseous and liquid fuels remain in the development stage and require continued federal support.

PROGRAM HISTORY

Biomass

The DOE Biomass Energy Technology Program began in 1976, but did not achieve a clear and consistent set of objectives or stable and competent management until about 1980. The budget history for the program is presented below:

Fiscal year:	
1976	5.14
1977	11.432
1978	21.186
1979	42.4
1980	33.0
1981	27.2
1982	20.5

(The Administration request for fiscal year 1983 was $6.6 million; the House Appropriations Committee provided $12 million; the Senate Appropriations Committee $16 million.)

Through 1980 the biomass program was structured around the traditional steps in the diffusion of innovation process—research and exploratory development, systems development and market development—with a heavy emphasis on systems development. In 1981 the program was reorganized into a form that is more relevant to the biomass energy technology development process. The program now contains two distinct activity groupings: Production Process R&D, which includes woody crops, herbaceous systems, aquatic biomass and wastes and residues; and Conversion Technology R&D, which includes thermochemical, biochemical and photobiological processes. The organizational elements are presented in Table 6-1 below, along with the most important research areas in each element.

Table 6-1 also presents the Administration's priorities for future research in the biomass area. All work on production processes will be eliminated in fiscal year 1983 except for research on the growth of microalgae. Near-term conversion technologies will also be dropped and all activities on longer-term conversion options will be limited to laboratory-scale research projects.

TABLE 6-1.—BIOMASS ENERGY RESEARCH OPPORTUNITIES [1]

Process area	Overall research options	Current DOE research activities	Future DOE research activities
Production processes:			
Wood	Conventional forestry	Conventional Forestry	
	Short-Rotation Woody Crops	Short-Rotation Woody Crops	
Herbaceous	Cellulosic Crops	Cellulosic Crops	
	Hydrocarbon-Bearing Crops	Hydrocarbon-Bearing Crops	
	Vegetable Oil-Bearing Crops	Vegetable Oil-Bearing Crops	
	Carbohydrate-Bearing Crops		
Aquatic	Microalgae	Microalgae	Microalgae.
	Macroalgae	Macroalgae	
	Emergent and Floating Plant Crops	Emergent and Floating Plant Crops	
Wastes and residues	Wood Wastes		
	Animal Manures		
	Food Processing Wastes		
	Municipal Wastes		
	Forest Residues		
	Agricultural Residues		
Conversion processes:			
Thermochemical	Combustion of Wood	Combustion of Wood	
	Gasification	Gasification	
	Liquefaction	Liquefaction	Liquefaction
	Pyrolysis	Pyrolysis	Pyrolysis.
Biochemical	Pretreatments	Pretreatments	Pretreatments
	Anaerobic Digestion	Anaerobic Digestion	Anaerobic Digestion.
	Fermentations		
Photobiological	Microorganisms	Microorganisms	Microorganisms
	Cell Particles	Cell Particles	Cell Particles.

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[1] Research to identify and limit environmental effects is contained within each research option as appropriate.

Alcohol fuels

The DOE Office of Alcohol Fuels was created by Title II of the Energy Security Act of 1980 to administer the loan guarantee and financial assistance provisions of that Act and to serve as a focal point for national activities in an area which was, at the time, of intense public interest. Alcohol fuel R&D activities that had previously resided in the Biomass, Fossil Energy and Conservation programs were transferred to the Office of Alcohol Fuels. SERI was designated the lead laboratory for Alcohol Fuels R&D and has taken the lead role in both managing and performing the research.

The Alcohol Fuels R&D program is divided into two primary activity areas: alcohol production process research and alcohol utilization research. Under process research the following activities are funded:

Ethanol process research, including acid hydrolysis, medium temperature enzymatic hydrolysis and high-temperature enzymatic hydrolysis (first, second and third generation technologies) for converting cellulosic feedstocks to ethanol.

Methanol process research, including development of an oxygen gasifier to produce syngas for methanol conversion and investigation of advanced catalysts and reactions.

Support research, which, according to SERI, "concentrates on process improvements and cost reductions in the areas of separation of alcohol and water, pretreatments and by-product utilization."

Research management, to fund high risk research on advanced concepts and cost reductions.

Process evaluation, a support task to analyse and evaluate new production processes and problem areas in current processes.

Under utilization research the program funds two activities:

Advanced engine research, to "investigate very high-efficiency alcohol utilization systems", including advanced engines and combustion turbines.

Advanced methanol fuel cell research, which investigates alternative electrolytes for direct methanol fuel cells at various temperatures". (quotations are from SERI Institutional Plan, fiscal year 1982–87).

The Alcohol Fuels R&D Budget began at $22 million in fiscal year 1980 and has decreased substantially since, falling to $18 million in fiscal year 1981 and $10 million in fiscal year 1982. The Administration proposed a close-out budget of $2.94 million for fiscal year 1983 with a termination of all program activities in fiscal year 1984. Both Appropriations Committees approved a budget of $5 million for the program for fiscal year 1983.

RECOMMENDATIONS

The magnitude of the potential contribution of energy from biomass feedstocks to the Nation's economy is great enough to justify a continued Federal research and technology development effort in both production and conversion processes. Although a number of biomass "industries" exists, including manufacturers of conversion systems and components, producers and chemicals and fuels, a wood stove and wood supply industry and industrial users, such as the forest products industry, they are too widespread and fragmented to assume all of the research and development activities that are being proposed for termination by the Administration. A continuation of both the Biomass and the Alcohol Fuels program at close to their fiscal year 1982 funding levels with the same mix of program activities would be a prudent and cost-effective Federal investment which would not duplicate efforts of the private sector. A detailed discussion of each program follows below.

Biomass production processes

The Administration decision to terminate all research and development related to feedstock production processes, with the exception of microalgae, runs directly counter to the recommendations of experts who have reviewed the Biomass program. The OTA Report on "Energy From Biological Processes" (July 1980) recommended the following R&D activities to be carried out with respect to the "Resource Base":

> *Wood harvesting.*—A repertoire of wood-harvesting techniques and equipment should be developed.
>
> *Surveys.*—Surveys should be conducted to determine more accurately the biomass resource . . .
>
> *Crop switching.*—Various crop-switching possibilities that involve fuel production should be investigated further.
>
> *Crop development.*—A wide variety of crop types should be developed, including grasses, legumes and trees; freshwater and saltwater plants; plants that produce or can be converted to liquid fuels suitable for transportation; and plants that can be cultivated on lands that are or may become unsuitable for food or feed production.
>
> *Ocean farms.*—R&D into the engineering criteria for ocean kelp farms is needed . . .
>
> *Environmental impacts of biomass cultivation.*—(This is only a partial listing.)

The ERAB Biomass panel report (November, 1981) stated that:

> Biomass energy potentials are primarily constrained by limits on agricultural and forest production and by the necessity to maintain a productive and high quality environment.

Accordingly, the ERAB Biomass panel made the following production-related research recommendations:

> 1. Make an accurate determination of biomass resource availability.
>
> 2. Investigate the potential of increasing biomass production. Investigate the genetics of crop and forest plants for increased productivity. Investigate new plant species to determine their potential for biomass energy production. Develop new collecting and harvesting technologies for forest and agricultural lignocellulosic materials. (This is only a partial listing.)

Since both of these reports were available to the Department of Energy before it prepared its fiscal year 1983 budget, it is difficult to determine on what analytical ground the decision to eliminate production process R&D was made.

The decision to terminate the "short rotation woody crops" activity, a university-based research program which appears entirely consistent with the Administration's philosophy of supporting long-term, high-risk, high payoff research is of special concern. According to DOE program documents, short rotation woody crops can "increase biomass yields from trees by factors of 5 to 10 times conventional forestry yields." Research is needed, according to the program, to "screen and genetically improve species and to identify cost-effective cultivation and harvesting techniques". "Several pilot and demonstration plots will be required in different areas of the country to prove economic feasibility," the document adds.

According to testimony by the project manager, Dr. Jack Ranney of Oak Ridge National Laboratory, the short rotation woody crops project has just completed its first harvest and is ready for a second round of plantings. Premature termination of the program would result in a loss of meaningful data on the gains that can be achieved by the genetic selection of species; the effectiveness of different management approaches; the costs and benefits of short-rotation intensive culture over several growing cycles; and a "solid economic evaluation" of the entire concept.

It is difficult to perceive the national benefits of terminating a modest program that is consistent with Administration philosophy and not duplicated in the private sector before meaningful results have been fully achieved.

Similar concerns must be raised with respect to plans to terminate programs in herbaceous crops and wastes and residues. According to DOE program documents, research needs related to herbaceous crops include "species screening, genetic improvement, and development of suitable cultivation methods" as well as "eventual pilot and demonstration plantings". The ERAB Solar R&D Panel adds that the "Federal Government should conduct basic research in expanding the resource base of both terrestrial and aquatic plants though plant species screening and selection, cataloging of plant components (and) insect and disease management . . ." With respect to wastes and residues, "new systems and equipment must be designed and developed to make harvesting economical while minimizing environmental impacts".

The herbaceous species R&D program should continue through the pilot planting phase, and a modest technology development and testing program for innovative waste and residue harvesting equipment should be initiated.

Biomass conversion processes

The Administration apparently intends to maintain a fairly broad research program related to conversion processes, but only on the basic research level, and only applied to longer term conversion options. The recommendations of the ERAB Biomass panel should be followed: DOE should "sponsor lignocellulose-to-fuel research and development projects at a sufficiently high level of determine within the next 5 years the practicality of using this energy source." This should include the "development of both efficient large-scale biological and small-scale thermochemical processes." In addition, as Dr. John Stinson of TVA recommended, pilot plants, at about a tenth of the size of a small commercial unit, must be built in order to give the private sector an accurate idea of the ultimate costs and performance of the biomass conversion systems.

In sum, in the conversion area, technology development efforts should be continued through the pilot plant stage for medium-Btu gasification systems, and should be initiated for liquefaction, pyrolysis, anaerobic digestion and biological production of hydrogen when laboratory results have identified a potentially attractive process. A recommended budget for the overall biomass energy technology program for fiscal year 1984 is presented below. It is believed that all activities should continue through fiscal year 1987 within the same overall budget level, but with changes in emphasis to reflect developments within each of the technology areas.

Table 6-2.—A recommended for biomass, fiscal year 1984

	Millions
Feedstock production process R&D:	
Short rotation woody crops	$4.0
Aquatic species	2.5
Herbaceous crops	3.0
Harvesting techniques	1.0
Subtotal	10.5
Conversion technology R&D:	
Biochemical conversion (including anaerobic digestion)	1.5
Thermochemical conversion (including gasification, liquefaction and pyrolysis)	6.0
Biological hydrogen production	1.5
Supporting research	2.0
Subtotal	12.0
Total biomass	22.5

Alcohol fuels

The SERI Alcohol Fuels program is a well-managed activity which is producing important results. Because of the importance of liquid fuels for transportation, the history of the program and the uniqueness of alcohol production processes, the program could be maintained as a separate entity from the biomass energy technology effort. The emphasis on conversion of cellulosic and lignocellulosic resources to ethanol and methanol should be maintained and the production process research program should be continued at its current funding level.

Advanced engine and fuel cell research would appear to be the proper domain of the Transportation Conservation and Fuel Cell programs, and should be returned to those areas.

A total budget of $7.5 million a year appears warranted for the Alcohol Fuels Production Process R&D program over the next four years.

CHAPTER VII.—WIND SYSTEMS PROGRAM

PROGRAM HISTORY

Since 1973 the United States Government has sponsored research and development in wind energy, in order to make wind turbines a viable technological alternative to existing electrical generating capacity. The current DOE Wind Energy Program, under the sponsorship of the Department of Energy, is directed toward the development and production of safe, reliable, cost-effective machines which will generate significant amounts of electricity.

The wind turbine program has developed a series of machines of increasing size and cost-effectiveness, beginning with the MOD-OA (200 KW, 4 machines installed in Hawaii, New Mexico, Rhode Island and Puerto Rico), the MOD-1 (1 MW, Boone, North Carolina) and the MOD-2 (2.5 MW, 3 machines installed at Goldendale, Washington). The large machine program will terminate with the MOD-5A and MOD-5B, two machines in the 3-7 MW range being built by Boeing and General Electric.

Each successive generation of technology has shown potential to increase reliability and energy capture, while reducing the cost of electricity. These advances were brought about by increased size, better understanding of the factors driving system design, improved analytical tools, verification of design methods with operational field data, and incorporating new technology into the machines.

The engineering development projects were supported by substantial analysis and hardware testing, including structural dynamic analysis, assessment of utility interface problems, testing of component materials, and testing and evaluation of new blade concepts.

In the small wind area, the government has supported the development of a series of wind turbines from 1-40 KW in size. In addition, the government has operated a test facility for small wind machines at Rocky Flats, Colorado. At the beginning of the government program, there were several small manufacturers of small wind turbines and several distributors who sold small foreign manufactured machines. Currently there are approximately 40 U.S. companies actively developing and marketing small machines.

The DOE program has also been active in developing and testing vertical axis (Darrieus) wind machines. A wind characteristics program has led to the publication of 12 wind atlasses containing detailed resource assessments for all 50 states, and siting handbooks to assist wind energy equipment installers. The program has also carried out market and economic studies; assessments of the environmental and institutional issues facing the deployment of wind energy systems; analysis of innovative concepts and information dissemination and technology transfer activities. A history of program funding for the various subprogram activities from 1973–78 and from 1979 to 1982 is provided in Tables 7–1 and 7–2 below.

TABLE 7–1.—PROGRAM FUNDING: FISCAL YEAR 1973–74 TO FISCAL YEAR 1978 (×1,000)

[Fiscal years]

Program elements/subelements	1973–74	1975 [1]	1976	Transition quarter [2]	1977	1978	Cumulative totals
1. Program development and technology	429	5,605	7,698	2,987	7,925	6,762	31,406
1.1 Mission analysis	12	1,043	831	371	1,272	745	4,274
1.2 Applications of wind energy		579	556	230	160	25	1,550
1.3 Legal/social/environmental issues		422	200	300	199	95	1,216
1.4 Wind characteristics	14	399	992	669	1,900	2,320	6,294
1.5 Technology development	279	2,281	3,069	364	2,650	2,707	11,350
1.6 Advanced systems	124	881	2,050	1,053	1,744	870	6,722
2. Farm and rural use (small) systems		736	1,507	231	2,641	7,669	12,784
3. 100 kw scale systems	865	970	1,439	628	1,444	3,573	8,919
4. MW scale systems	500	600	3,140	832	12,465	14,450	31,987
5. Large multiunit systems			582	292	25	1,497	2,396
Totals	1,794	7,911	14,366	4,970	24,500	34,036	87,577
Capital equipment and construction					3,100	1,421	4,521
Totals					27,600	35,053	62,653

[1] Includes NSF funding.

[2] Transition quarter (July-September 1976).

TABLE 7–2.—PROGRAM FUNDING: FISCAL YEAR 1979 TO FISCAL YEAR 1982(ESTIMATE) (×1,000)

[Fiscal years]

Program elements	1979	1980	1981	1982 (estimate)	Cumulative totals
1. Planning, management and analysis	5,015	6,217	7,450	1,525	20,207
2. Wind characteristics	4,374	4,842	6,000	2,250	17,466
3. Technology development	9,800	12,184	18,500	10,011	50,495
4. Engineering development	33,935	19,443	33,200	19,914	106,492
5. Implementation and market development	5,031	2,574	4,750		12,355
Totals	58,155	45,260	69,900	33,700	207,015
Capital equipment and construction	1,400	18,140	7,600	700	2,784
Totals	59,555	63,400	77,500	34,400	234,855

For fiscal year 1983, the Administration requested $5.5 million, but Congress appropriated $31.4 million, with most of the increase being for continued engineering development (at 50/50 cost sharing with industry) of the two MOD–5 machines ($18 million) and continued operation, testing and repair of the three MOD–2 machines at Goldendale, Washington ($5.7 million). The breakdown of the fiscal year 1983 budget is as follows:

Table 7–3.—Wind systems fiscal year 1983 budget

	Million
Aerodynamic research (develop and improve generic aerodynamic and load predictions for wind turbines)	$2.5

	Million
Structural research (validate generic structural analysis computer models; undertake fatigue life research studies[1]	2.4
Experimental systems (repair and research testing of MOD-2's; continued prototype design and engineering activities on MOD-5)	23.7
Small systems test center (Rocky Flats)	2.0
Wind Systems Act studies/reports [1]	0.7
Capital Equipment	0.1
Total	31.4

[1] The Wind Energy Systems Act of 1980 (Public Law 96-345), passed by Congress at the initiation of the House Committee on Science and Technology, set the following goals for wind energy technologies:

"To reduce the average cost of electricity produced by installed wind systems by the end of fiscal year 1988 to a level competitive with conventional energy sources.

"To reach a total wind energy systems capacity of 800 MW (100 from small machines) by 1988.

"To accelerate the growth of a commercially viable and competitive industry.

"To displace 1.7 quads of energy per year by the year 2000."

The act called for an agressive research, development and demonstration program, a technology applications program (grants, loans and federal procurement), a wind resource assessment program and an applications study program to support those goals.

FUTURE DIRECTIONS

The goal of the DOE large wind turbine program has been to develop a machine that is competitive with conventional energy systems at a wide variety of sites in moderate to good wind regimes. Current technology is only competitive with high priced alternatives in exceptionally favorable wind regimes. The MOD-5 machine, with projected costs of energy in the 4-6 ¢/kwhr range, is the most likely candidate for meeting those goals.

The large machine program has experienced a number of setbacks this past year, including structural failure of the main load bearing shaft on the MOD-2; cancelling of a planned MOD-2 wind farm project by Boeing and PG&E and a proposal by NASA to terminate wind energy systems activities at the Lewis Research Center. Because of these setbacks, the engineering development program on the MOD-5, which was scheduled for completion in fiscal year 1984, will have to be continued through fiscal year 1985. To insure that the program goals are met, and that the federal investment of more than $130 million in large machine technology is realized, it is essential that the MOD-5 program be competed through the fabrication and testing of both the MOD-5A and the MOD-5B.

Once the MOD-5 program is completed the federal program can terminate its engineering development activities and focus on aerodynamic and structural research to support industry. NASA Lewis should continue its role as lead national laboratory for horizontal axis machine R&D and Sandia should retain management of vertical axis R&D activities. Component development and testing to support new approaches to lowering costs or improving performance should be initiated when requested by industry, with industry cost-sharing. Test facilities and machines should be maintained to carry out these activities.

The DOE aerodynamic and structural research programs have historically been divided rather evenly between vertical and horizontal axis technology. However, it is not clear that private industry intends to commercialize vertical axis systems and therefore further Federal support for this technology may not be warranted.

DOE should do an assessment of the desirability of continuing vertical axis support activities, and possibly phase out the program if industry commitment does not appear to be forthcoming.

Aerodynamic and structural research activities can lack direction and focus if not linked to the design of new and improved machines. The historic focus of the DOE program on very large and very small machines has left a gap in the intermediate range (100–500 KW) which it may be desirable to fill. Intermediate sized machines offer the advantages of potential cost-of-energy reductions over small machines and lower developmental, technical and financial risk over large machines. Therefore, to focus the R&D programs and fill this gap, it may be desirable for DOE to cost share with industry the design and testing of an advanced intermediate sized machine (vertical or horizontal axis) in the 1985 time frame. Such a project would only be funded if major innovations offered the potential for significant advances in cost effectiveness.

Continued operation of the Rocky Flats test center for small wind machines needs to be reassessed. The facility is expensive to operate and has a highly erratic wind regime, varying from little or no wind over much of the year to very high winds with destructive cross-currents. Moreover, it is not clear that the small wind industry desires to support such a facility on a continuing basis. DOE should do an assessment, with input from industry, of the following three options:

1. Termination of all small wind system testing activities;
2. Continuation of Rocky Flats activities with gradual phase out of federal support and gradual assumption of the full cost of operating the facility by industry.
3. Cost-sharing development and operation of a new test site in a more realistic wind regime, such as at West Texas University, where the current USDA testing program is carried out.

Resource assessment has been recommended by several observers, including the ERAB Solar R&D Panel, as a proper federal role. While the wind resource atlases published by the program are detailed and comprehensive they do not contain the site-specific data needed to determine the feasibility of particular wind projects. A de-centralized site prospecting program to provide assistance to utilites, local governments and other entities in assessing the potential for wind energy applications in specific regions may be justified.

Finally, DOE should take the lead in assuring that all federal agencies including itself, are purchasing wind energy systems where cost-effective on a life cycle cost basis. If the renewable energy business tax credits are extended to 1990 the private sector should be able to take care of wind systems commericalization on its own. If not, DOE may have to consider implementing the test and applications provisions of the Wind Energy Systems Act. A proposed budget for fiscal year 1984–1987 is presented below:

TABLE 7-3.—PROPOSED WIND SYSTEMS BUDGET FOR FISCAL YEARS 1984-87

[In millions of dollars]

	1984	1985	1986	1987
Aerodynamics research	$3.6	$4.0	$4.0	$3.0
Structural research	3.5	4.0	4.0	3.0
Small wind test center	1.5	1.0		
Completion of MOD-5	14.0	10.0	4.0	
Design and testing of advanced intermediate machine			2.0	8.0
Resource assessment			2.0	2.0
Total	22.6	19.0	16.0	16.0

CHAPTER VIII.—OCEAN THERMAL ENERGY CONVERSION PROGRAM

PROGRAM HISTORY

The concept of utilizing ocean temperature differences to generate electricity is not new. It was first proposed about one hundred years ago by Arsene d'Arsonval, a French physicist, who suggested using a substance with a low boiling point as the working fluid in a closed-cycle system. The first experimental studies were made by the French inventor Georges Claude and reported in 1930. In these experiments, conducted off the coast of Cuba, seawater was used as the working fluid in an open-cycle system.

Impending worldwide energy shortages spurred renewed interests in ocean thermal energy, and OTEC is now under development in a number of countries. The most ambitious program so far is the one conducted by the United States Department of Energy, with cumulative funding of over $200 million. The funding history is shown in Table 8–1. In Hawaii, a United States industrial consortium funded and successfully operated a small experimental pilot project, called Mini-OTEC, in conjunction with the State Government. Other development programs are being carried out by the governments of France and Japan.

The basic requirement for an OTEC plant is access to ocean waters having sufficient temperature difference (typically about 20 degrees Celsius) between the surface and depths of about 1,000 meters. At certain locations, facilities could be built on shore, but in general, adequate thermal gradients are accessible only at sea, mainly at tropical and subtropical latitudes. Electric power generated at sea can be transmitted to shore via submarine cable or used for manufacturing operations on the platform, with production of such energy-intensive, substances as aluminum, ammonia, hydrogen, chlorine, or magnesium.

The size of OTEC plants could readily be adjusted to match commercial applications. It is likely that the size would range from about 10 MW to about 500 MW. Plants would be modular, and their limiting size would probably be determined by the ability to construct and deploy large ocean platforms cost-effectively.

OTEC power is one of the few solar energy options (hydropower and biomass are others) that can provide a source of baseload electricity, available on a continuous basis. Accordingly, OTEC-derived electricity needs to be cost competitive with electricity from other baseload sources, such as oil-fired, coal-fired, and nuclear power plants.

Since fuel is not required for plant operation, the major costs are for amoritization of the capital investment, operations and maintenance.

The OTEC program has been designed to address the technical and environmental obstacles to commercial application. To further this objective Congress enacted the "Ocean Energy Conversion Research, Development, and Demonstration Act" (Public Law 96-310), July 17, 1980. This act set goals to be achieved by government and industry, as follows:

Demonstration by 1986 of at least 100 MW of capacity from OTEC systems;

Demonstration by 1989 of at least 500 MW of OTEC capacity;

Cost competitiveness with conventional energy sources by the mid 1990's in the Gulf Coast and island markets;

Installation of 10,000 MW of commercial OTEC capacity by 1999.

TABLE 8-1.—OTEC FUNDING HISTORY

(BA $ in millions)

	Prior years	Fiscal years—			
		1976	1977	1978	1979
Program element:					
Program support	0.1	2.1	2.1	2.5	
Definition planning	2.5	2.7	1.2	1.6	6.7
Engineering development		0.3	3.4	10.9	11.6
Engineering test and evaluation			3.3	13.3	16.6
Advanced research and technology	1.4	3.5	4.5	7.7	3.3
Subtotal	4.0	8.6	14.5	36.0	38.2
Construction funds reprogramed from fiscal years 1978 to 1979				−4.8	+48
Total	4.0.	[1]8.6	14.5	31.2	43.8

	Fiscal years—			
	1980	1981	1982	1983
Program element:				
Basic research				
Applied research				
Exploratory development	3.1	4.2	5.395	
Technology development	16.8	14.3	6.850	4.5
Engineering development	20.1	20.5	8.555	10.0
Demonstration				
Commercialization				
Total	40.0	39.0	20.8	14.5

[1] Includes transition quarter funding.

CURRENT AND FUTURE ACTIVITIES

OTEC concepts raise a series of technological issues related to heat exchangers and their operation, that is, deployment and maintenance of a long cold water pipe, optimum station type and operation in a hostile open ocean environment, unique turbine types, and means of getting energy (or product) to place of use. All of these issues require the development, construction and testing of unique and expensive hardware.

The question that is key to the future of this government program is, "Is the market of OTEC viable?" In other words, could OTEC systems, or the energy from these systems, be sold to customers that are able to pay for the product? In the geographic areas where OTEC can be utilized (generally in the tropics) only the states of Florida and Hawaii appear to offer a viable market.

The second issue is, "Can OTEC be made economically competitive with other sources of energy?" The likely costs of the fundamental pieces of hardware in the closed cycle system, such as heat exchangers, cold water pipes, platform and cables, are so large it is difficult to envision that the systems as a whole can be competitive.

In order to answer the question of economic viability, the government has funded two competing contractors to do conceptual designs of closed cycle shore mounted systems. One of these designs will be funded through the preliminary design phase, which should provide a satisfactory basis for an investment decision by the private sector. Shore based systems were selected to minimize the technological risk and cost to build the systems, thus providing OTEC with its best opportunity to prove its economic viability with a minimum cost to the government.

With funding of the preliminary design for at least one OTEC pilot plant, and associated hardware-related research and development, the closed-cycle program can come to a logical termination point in fiscal year 1983. However, there appears to be a potential for lowering the cost and improving the efficiency of OTEC systems by moving to advanced power conversion concepts. One such concept, the open-cycle system, in which sea water is allowed to evaporate and drive a turbine directly, appears especially promising. An open cycle system would eliminate the need for costly and relatively inefficient heat exchangers, thus improving the potential for ultimate system cost-effectiveness. Thus, it is recommended that DOE begin a multi-year program on open-cycle OTEC and other advanced conversion concepts.

The following five year program is proposed, based on current knowledge of the technology and economics, plus consideration of the facilities available and the program's sunk costs.

1. Continue the development of the Seacoast Test Facility (STF) to provide a base for a 1 MW size test of the open cycle.
2. Design and build a 1 MW size experimental open cycle system to be installed and tested at STF.
3. Conduct continued research on thermal cycles applicable to low temperature difference sources with the goal of reducing costs in a variety of applications.

TABLE 8-2.—PROPOSED OTEC BUDGET FOR FISCAL YEARS 1984–87

[By fiscal year, in millions of dollars]

	1984	1985	1986	1987
Prepare seacoast test facility by installing seawater pipes and pumps for a 1 MW size experiment	2.0	1.0		
Operate seacoast test facility experiments		1.0	1.5	1.5
1 MW open cycle system design, build and test	5.0	5.0	3.0	1.0
Conduct research on thermal cycles applied to low temperature difference sources	1.0	2.0	2.0	2.0
Total	8.0	9.0	6.5	4.5

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